ATTACHMENT 29

Risk Assessment Guidance for Superfund, Volume I
Human Health Evaluation Manual
(Part B, Development of Risk-Based
Preliminary Remediation Goals)
Publication 9285.7-01B
December 1991

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

DEC 13 1991

OFFICE OF
SOLID WASTE AND EMERGENCY RESPONSE

OSWER Directive 9285.7-01B

MEMORANDUM

SUBJECT: Human Health Evaluation Manual, Part B:
"Development of Risk-based Preliminary Remediation
Goals"

FROM: Henry Longest II, Director
Office of Emergency and Remedial Response

Bruce Diamond, Director
Office of Waste Programs Enforcement

TO: Regional Waste Management Division Directors

Purpose

The purpose of this directive is to transmit the Risk
Assessment Guidance for Superfund (RAGS), Human Health Evaluation
Manual, Part B: "Development of Risk-based Preliminary
Remediation Goals" to be used in the remedial investigation and
feasibility study (RI/FS) process. This guidance supplements the
Human Health Evaluation Manual, Part A--Baseline Risk Assessment,
and Part C--Risk Evaluation of Remedial Alternatives.

Background

As a first step in the FS, section 300.430(e) of the
National Oil and Hazardous Substances Pollution Contingency Plan
(NCP) calls for the development of remedial action objectives and
preliminary remediation goals (PRGs). As part of the revision to
the 1986 Superfund Public Health Evaluation Manual, a workgroup
was formed to define the role of risk assessment in setting PRGs.
The interim guidance distributed today incorporates numerous
comments received over the last two years from Regional and
Headquarters management on the role of risk and ARARs in the goal
setting process.

Objective

The process outlined in this guidance will aid RPMs, site engineers and risk assessors in developing PRGs that satisfy the "threshold criteria" of the NCP: protection of human health and the environment, and compliance with ARARs. These goals are typically formulated during the initial stages of the RI/FS to focus the development of remedial alternatives on technologies that may achieve appropriate target levels, thereby limiting the number of alternatives analyzed and streamlining the process. As this guidance advocates the use of health-based ARARs as PRGs, it should be used in conjunction with the "CERCLA Compliance with Other Laws Manual" and the "ARARs Q's and A's" fact sheet series.

The Regional Risk Management Workgroup is addressing several issues regarding the role of ARARs and cumulative site risk in the goal-setting process that are considered outside the scope of this risk assessment guidance. Supplemental guidance will be developed as these risk management issues are successfully resolved.

Implementation

This document is being distributed as _interim_ guidance pending review of the RAGS series by the Science Advisory Board (SAB). It is our intention to begin updating and consolidating the series in FY 92. At that time, we will incorporate SAB's comments and the results of ongoing, EPA-sponsored research projects. We also strongly urge RPMs and Regional risk assessors to contact the Toxics Integration Branch of the Office of Emergency and Remedial Response (FTS 260-9486) with any suggestions for further improvement.

Attachment

cc: Regional Branch Chiefs
    Regional Section Chiefs
    Regional Toxics Integration Coordinators
    Workgroup Members

Risk Assessment Guidance for Superfund: Volume I — Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals)

Interim

NOTICE

The policies set out in this document are intended solely as guidance; they are not final U.S. Environmental Protection Agency (EPA) actions. These policies are not intended. nor can they be relied upon. to create any rights enforceable by any party in litigation with the United States. EPA officials may decide to follow the guidance provided in this document. or to act at variance with the guidance. based on an analysis of specific site circumstances. The Agency also reserves the right to change this guidance at any time without public notice.

This guidance is based on policies in the Final Rule of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), which was published on March 8, 1990 (55 *Federal Register* 8666). The NCP should be considered the authoritative source.

CONTENTS

EXHIBITS

DEFINITIONS

Term	Definition
Applicable or Relevant and Appropriate Requirements (ARARs)	"Applicable" requirements are those clean-up standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) site. "Relevant and appropriate" requirements are those clean-up standards which, while not "applicable" at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well-suited to the particular site. ARARs can be action-specific, location-specific, or chemical-specific.
Cancer Risk	Incremental probability of an individual's developing cancer over a lifetime as a result of exposure to a potential carcinogen.
Conceptual Site Model	A "model" of a site developed at scoping using readily available information. Used to identify all potential or suspected sources of contamination, types and concentrations of contaminants detected at the site, potentially contaminated media, and potential exposure pathways, including receptors. This model is also known as "conceptual evaluation model".
Exposure Parameters	Variables used in the calculation of intake (e.g., exposure duration, inhalation rate, average body weight).
Exposure Pathway	The course a chemical or physical agent takes from a source to an exposed organism. An exposure pathway describes a unique mechanism by which an individual or population is exposed to chemicals or physical agents at or originating from a site. Each exposure pathway includes a source or release from a source, an exposure point, and an exposure route. If the exposure point differs from the source, a transport/exposure medium (e.g., air) or media (in cases of intermedia transfer) also would be indicated.
Exposure Point	A location of potential contact between an organism and a chemical or physical agent.
Exposure Route	The way a chemical or physical agent comes in contact with an organism (i.e., by ingestion, inhalation, dermal contact).
Final Remediation Levels	Chemical-specific clean-up levels that are documented in the Record of Decision (ROD). They may differ from preliminary remediation goals (PRGs) because of modifications resulting from consideration of various uncertainties, technical and exposure factors, as well as all nine selection-of-remedy criteria outlined in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP).

DEFINITIONS (Continued)

Term	Definition
Hazard Index (HI)	The sum of two or more hazard quotients for multiple substances and/or multiple exposure pathways.
Hazard Quotient (HQ)	The ratio of a single substance exposure level over a specified time period to a reference dose for that substance derived from a similar exposure period.
"Limiting" Chemical(s)	Chemical(s) that are the last to be removed (or treated) from a medium by a given technology. In theory, the cumulative residual risk for a medium may approximately equal the risk associated with the limiting chemical(s).
Preliminary Remediation Goals (PRGs)	Initial clean-up goals that (1) are protective of human health and the environment and (2) comply with ARARs. They are developed early in the process based on readily available information and are modified to reflect results of the baseline risk assessment. They also are used during analysis of remedial alternatives in the remedial investigation/feasibility study (RI/FS).
Quantitation Limit (QL)	The lowest level at which a chemical can be accurately and reproducibly quantitated. Usually equal to the method detection limit multiplied by a factor of three to five, but varies for different chemicals and different samples.
Reference Dose (RfD)	The Agency's preferred toxicity value for evaluating potential noncarcinogenic effects in humans resulting from contaminant exposures at CERCLA sites. (See RAGS/HHEM Part A for a discussion of different kinds of reference doses and reference concentrations.)
Risk-based PRGs	Concentration levels set at scoping for individual chemicals that correspond to a specific cancer risk level of 10^{-6} or an HQ/HI of 1. They are generally selected when ARARs are not available.
Slope Factor (SF)	A plausible upper-bound estimate of the probability of a response per unit intake of a chemical over a lifetime. The slope factor is used to estimate an upper-bound probability of an individual's developing cancer as a result of a lifetime of exposure to a particular level of a potential carcinogen.
Target Risk	A value that is combined with exposure and toxicity information to calculate a risk-based concentration (e.g., PRG). For carcinogenic effects, the target risk is a cancer risk of 10^{-6}. For noncarcinogenic effects, the target risk is a hazard quotient of 1.

ACRONYMS/ABBREVIATIONS

Acronym/ Abbreviation	Definition
ARARs	Applicable or Relevant and Appropriate Requirements
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CWA	Clean Water Act
EAG	Exposure Assessment Group
ECAO	Environmental Criteria and Assessment Office Superfund Health Risk Technical Support Center
EF	Exposure Frequency
EPA	U.S. Environmental Protection Agency
FWQC	Federal Water Quality Criteria
HEAST	Health Effects Assessment Summary Tables
HHEM	Human Health Evaluation Manual
HI	Hazard Index
HQ	Hazard Quotient
HRS	Hazard Ranking System
IRIS	Integrated Risk Information System
LLW	Low-level Radioactive Waste
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NPL	National Priorities List
OSWER	Office of Solid Waste and Emergency Response
OERR	Office of Emergency and Remedial Response

ACRONYMS/ABBREVIATIONS (Continued)

Acronyms/ Abbreviation	Definition
PA/SI	Preliminary Assessment/Site Inspection
PEF	Particulate Emission Factor
PRG	Preliminary Remediation Goal
RAGS	Risk Assessment Guidance for Superfund
RCRA	Resource Conservation and Recovery Act
RfC	Reference Concentration
RfD	Reference Dose
RI/FS	Remedial Investigation/Feasibility Study
RME	Reasonable Maximum Exposure
ROD	Record of Decision
RPM	Remedial Project Manager
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SF	Slope Factor
TR	Target Risk
VF	Volatilization Factor
WQS	State Water Quality Standards

ACKNOWLEDGEMENTS

PREFACE

Risk Assessment Guidance for Superfund: *Volume I — Human Health Evaluation Manual* (RAGS/HHEM) Part B is one of a three-part series. Part A addresses the baseline risk assessment; Part C addresses human health risk evaluations of remedial alternatives. Part B provides guidance on using U.S. Environmental Protection Agency (EPA) toxicity values and exposure information to derive risk-based preliminary remedial goals (PRGs) for a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) site. Initially developed at the scoping phase using readily available information, risk-based PRGs generally are modified based on site-specific data gathered during the remedial investigation/feasibility study (RI/FS). This guidance does not discuss the risk management decisions that are necessary at a CERCLA site (e.g., selection of final remediation goals). The potential users of Part B are those involved in the remedy selection and implementation process, including risk assessors, risk assessment reviewers, remedial project managers, and other decision-makers.

This manual is being distributed as an interim document to allow for a period of field testing and review. RAGS/HHEM will be revised in the future, and Parts A, B, and C will be incorporated into a single final guidance document. Additional information for specific subject areas is being developed for inclusion in a later revision. These areas include:

- development of goals for additional land uses and exposure pathways;
- development of short-term goals;
- additional worker health and safety issues; and
- determination of final remediation goals (and attainment).

Comments addressing usefulness, changes, and additional areas where guidance is needed should be sent to:

U.S. Environmental Protection Agency
Toxics Integration Branch (OS-230)
Office of Emergency and Remedial Response
401 M Street, SW
Washington, DC 20460

Telephone: 202-260-9486
FAX: 202-260-6852

·CHAPTER 1

INTRODUCTION

The purpose of this guidance is to assist risk assessors, remedial project managers (RPMs), and others involved with risk assessment and decision-making at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites in developing preliminary remediation goals (PRGs). This guidance is the second part (Part B) in the series *Risk Assessment Guidance for Superfund: Volume I — Human Health Evaluation Manual* (RAGS/HHEM).

Part A of this series (EPA 1989d) assists in defining and completing a site-specific baseline risk assessment; much of the information in Part A is necessary background for Part B. Part B provides guidance on using U.S. Environmental Protection Agency (EPA) toxicity values and exposure information to derive risk-based PRGs. Initially developed at the scoping phase using readily available information, risk-based PRGs generally are modified based on site-specific data gathered during the remedial investigation/feasibility study (RI/FS). Part C of this series (EPA 1991d) assists RPMs, site engineers, risk assessors, and others in using risk information both to evaluate remedial alternatives during the FS and to evaluate the selected remedial alternative during and after its implementation. Exhibit 1-1 illustrates how the three parts of RAGS/HHEM are all used during the RI/FS and other stages of the site remediation process.

The remainder of this introduction addresses the definition of PRGs, the scope of Part B, the statutes, regulations, and guidance relevant to PRGs, steps in identifying and modifying PRGs, the communication and documentation of PRGs, and the organization of the remainder of this document.

1.1 DEFINITION OF PRELIMINARY REMEDIATION GOALS

In general, PRGs provide remedial design staff with long-term targets to use during analysis and selection of remedial alternatives. Ideally, such goals, if achieved, should both comply with applicable or relevant and appropriate requirements (ARARs) and result in residual risks that fully satisfy the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) requirements for the protection of human health and the environment. By developing PRGs early in the decision-making process (before the RI/FS and the baseline risk assessment are completed), design staff may be able to streamline the consideration of remedial alternatives.

Chemical-specific PRGs are concentration goals for individual chemicals for specific medium and land use combinations at CERCLA sites. There are two general sources of chemical-specific PRGs: (1) concentrations based on ARARs and (2) concentrations based on risk assessment. ARARs include concentration limits set by other environmental regulations (e.g., non-zero maximum contaminant level goals [MCLGs] set under the Safe Drinking Water Act [SDWA]). The second source for PRGs, and the focus of this document, is risk assessment or risk-based calculations that set concentration limits using carcinogenic and/or noncarcinogenic toxicity values under specific exposure conditions.

1.2 SCOPE OF PART B

The recommended approach for developing remediation goals is to identify PRGs at scoping, modify them as needed at the end of the RI or during the FS based on site-specific information from the baseline risk assessment, and ultimately select remediation levels in the Record of Decision (ROD). In order to set chemical-specific PRGs in a site-specific context, however, assessors must answer fundamental questions about the site. Information on the chemicals that are present onsite, the specific contaminated media, land-use assumptions, and the exposure assumptions behind pathways of individual exposure is necessary in order to develop chemical-specific PRGs. Part B provides guidance for considering this information in developing chemical-specific PRGs.

:

EXHIBIT 1-1

RELATIONSHIP OF THE HUMAN HEALTH EVALUATION
TO THE CERCLA PROCESS

CERCLA REMEDIAL PROCESS

Scoping	→	Remedial Investigation / Feasibility Study	→	Remedy Selection and Record of Decision	→	Remedial Design/ Remedial Action	→	Deletion/ Five-year Review

HUMAN HEALTH EVALUATION MANUAL

| PART A |
| Baseline Risk Assessment |

| PART B |
| Development of Risk-based Preliminary Remediation Goals |

| PART C |
| Risk Evaluation of Remedial Alternatives |
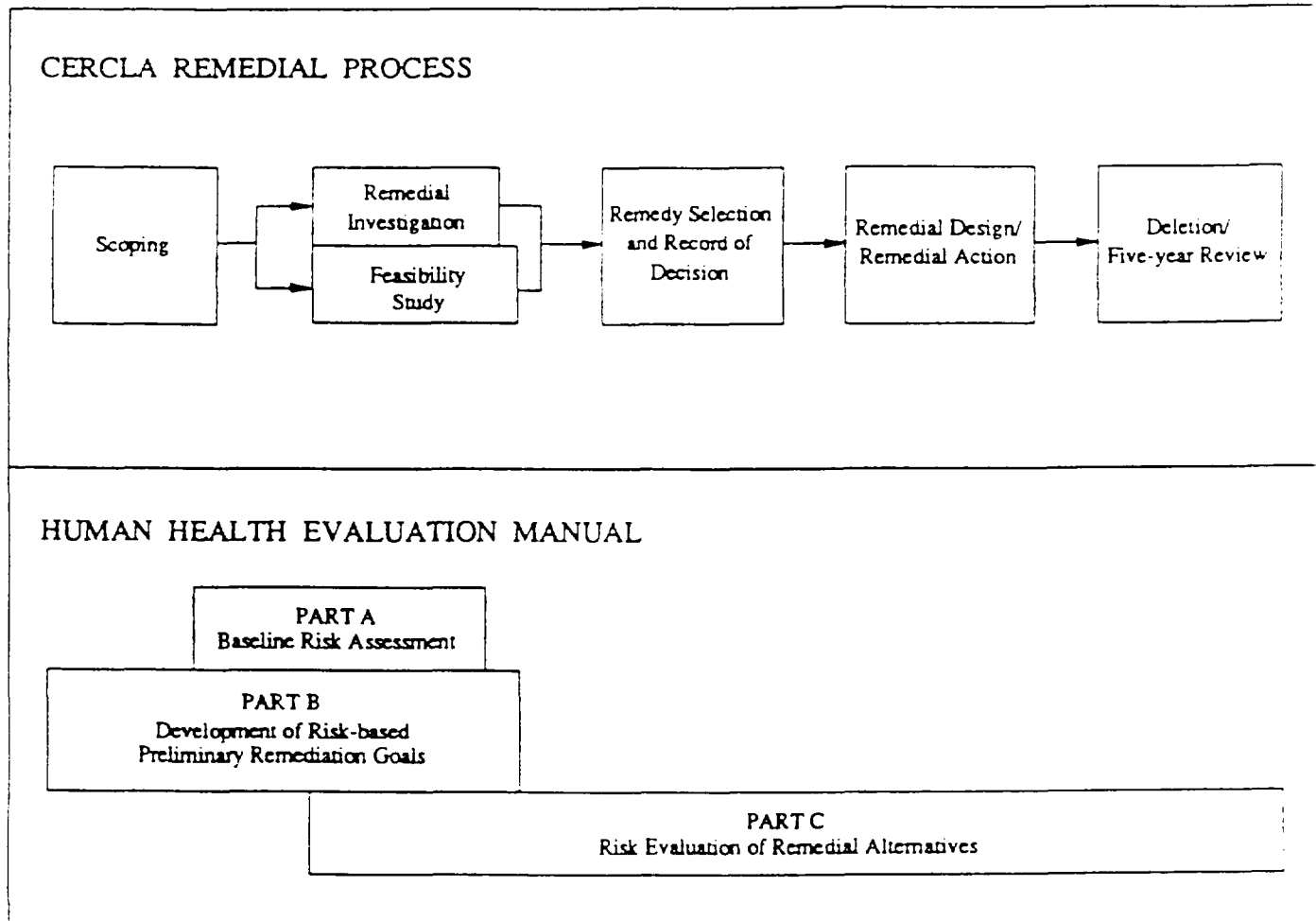
Because Part B focuses on developing chemical-specific PRGs based on protection of human health, there are important types of information that are not considered and that may significantly influence the concentration goals needed to satisfy the CERCLA criteria for selection of a remedy. For example, no consideration is given to ecological effects in this guidance. Other types of remedial action "goals" not addressed in detail include action-specific ARARs (e.g., technology- or performance-based standards) and location-specific ARARs.

Throughout Part B, the term "chemical-specific" should be understood to refer to both nonradioactive and radioactive chemical hazardous substances, pollutants, or contaminants. Therefore, the process described in this guidance of selecting and modifying PRGs at a site should be applied to each radionuclide of potential concern. Chapter 10 of RAGS/HHEM Part A provides background information concerning radionuclides, and Chapter 4 of RAGS/HHEM Part B includes radionuclide risk-based equations and a case study of a hypothetical radiation site.

This guidance only addresses in detail the initial selection of risk-based PRGs. Detailed guidance regarding other factors that can be used to further modify PRGs during the remedy selection process is presented in other documents (see Section 1.3).

1.3 RELEVANT STATUTES, REGULATIONS, AND GUIDANCE

This section provides relevant background on the CERCLA statute and the regulations created to implement the statute (i.e., the NCP). In addition, other CERCLA guidance documents are listed and their relationship to the site remediation process is discussed.

1.3.1 CERCLA/SARA

CERCLA, as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA), is the authority for EPA to take response actions. (Throughout this guidance, reference to CERCLA should be understood to mean "CERCLA as amended by SARA.")

Several sections of CERCLA, especially section 121 (Clean-up Standards), set out the requirements and goals of CERCLA. Two fundamental requirements are that selected remedies be protective of human health and the environment, and comply with ARARs. CERCLA indicates a strong preference for the selection of remedial alternatives that permanently and significantly reduce the volume, toxicity, or mobility of wastes. To the maximum extent practicable, the selected remedial alternatives should effect permanent solutions by using treatment technologies. Both the law and the regulation (see below) call for cost-effective remedial alternatives.

1.3.2 NATIONAL CONTINGENCY PLAN

Regulations implementing CERCLA are found in Volume 40 of the Code of Federal Regulations (CFR), Part 300, and are referred to collectively as the NCP. Section 300.430 of the NCP, and several portions of the preambles in the *Federal Register* (55 *Federal Register* 8666, March 8, 1990 and 53 *Federal Register* 51394, December 21, 1988), address how the Superfund and other CERCLA programs are to implement the Act's requirements and goals concerning clean-up levels.

Nine criteria have been developed in the NCP to use in selecting a remedy. These criteria are listed in the next box. The first criterion — overall protection of human health and the environment — is the focus of this document. This criterion coupled with compliance with ARARs are referred to as "threshold criteria" and must be met by the selected remedial alternative. PRGs are developed to quantify the standards that remedial alternatives must meet in order to achieve these threshold criteria. See the second box on the next page for highlights from the NCP on remediation goals.

1.3.3 GUIDANCE DOCUMENTS

There are several existing documents that provide guidance on related steps of the site remediation process. These documents are described in the box on page five. When documents are referenced throughout this guidance, the abbreviated titles, indicated in parentheses after the full titles and bibliographic information, are used.

1.4 INITIAL DEVELOPMENT OF PRELIMINARY REMEDIATION GOALS

The NCP preamble indicates that, typically, PRGs are developed at scoping or concurrent with initial RI/FS activities (i.e., prior to completion of the baseline risk assessment). This early determination of PRGs facilitates development of a range of appropriate remedial alternatives and can focus selection on the most effective remedy.

Development of PRGs early in the RI/FS requires the following site-specific data:

• media of potential concern;
• chemicals of potential concern; and
• probable future land use.

This information may be found in the preliminary assessment/site inspection (PA/SI) reports or in the conceptual site model that is developed prior to or during scoping. (When a site is listed on the National Priorities List [NPL], much of this information is compiled during the PA/SI as part of the Hazard Ranking System [HRS] documentation record.) Once these factors are known, all potential ARARs must be identified. When ARARs do not exist, risk-based PRGs are calculated using EPA health criteria (i.e., reference doses or cancer slope factors) and default or site-specific exposure assumptions.

It is important to remember that risk-based PRGs (either at scoping or later on) are initial guidelines. They do not establish that cleanup to meet these goals is warranted. A risk-based concentration, as calculated in this guidance, will be considered a final remediation level only after appropriate analysis in the RI/FS and ROD.

- *Risk Assessment Guidance for Superfund Volume 1 — Human Health Evaluation Manual Part A* (EPA 1989a) (RAGS/HHEM Part A) contains background information and is particularly relevant for developing exposure and toxicity assessments that are required when refining chemical-specific risk-based concentrations, and accounting for site-specific factors such as multiple exposure pathways.

- *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA 1988c) (RI/FS Guidance) presents detailed information about implementing the RI/FS and general information on the use of risk-based factors and ARARs in the context of the RI/FS.

- *Guidance on Remedial Action for Contaminated Ground Water at Superfund Sites* (EPA 1988d) (Ground-water Guidance) details some of the key issues in development, evaluation, and selection of ground-water remedial actions at CERCLA sites.

- *CERCLA Compliance with Other Laws Manuals* (Part I, EPA 1988a; and Part II, EPA 1989a) (CERCLA Compliance Manuals) provide guidance for complying with ARARs. Part I addresses the Resource Conservation and Recovery Act (RCRA), the Clean Water Act (CWA), and the SDWA; Part II addresses the Clean Air Act (CAA), other federal statutes, and state requirements.

- *Methods for Evaluating the Attainment of Cleanup Standards (Volume 1: Soils and Solid Waste)* (EPA 1989e) and *Methods for Evaluating the Attainment of Cleanup Standards (Volume 2: Water)* (Draft, 1988, EPA, Statistical Policy Branch) (Attainment Guidance) provide guidance on evaluating the attainment of remediation levels, including appropriate sampling and statistical procedures to test whether the chemical concentrations are significantly below the remediation levels.

- *Interim Final Guidance on Preparing Superfund Decision Documents* (EPA 1989b) (ROD Guidance) provides guidance that: (1) presents standard formats for documenting CERCLA remedial action decisions; (2) clarifies the roles and responsibilities of EPA, states, and other federal agencies in developing and issuing decision documents; and (3) explains how to address changes made to proposed and selected remedies.

- *Catalog of Superfund Program Publications*, Chapter 5 (EPA 1990a) lists all ARARs guidance documents that have been issued by EPA, shown in order of date of issuance.

- *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions* (EPA 1991c) provides clarification on the role of the baseline risk assessment in developing and selecting CERCLA remedial alternatives.

- *Guidance for Data Useability in Risk Assessment* (EPA 1990b) (Data Useability Guidance) provides guidance on how to obtain a minimum level of quality for all environmental analytical data required for CERCLA risk assessments. It can assist with determining sample quantitation limits (SQLs) for chemical-specific analyses.

- *Guidance on Remedial Actions for Superfund Sites with PCB Contamination* (EPA 1990c) describes the recommended approach for evaluating and remediating CERCLA sites having PCB contamination.

- *Conducting Remedial Investigations/Feasibility Studies for CERCLA Municipal Landfill Sites* (EPA 1991a) (Municipal Landfill Guidance) offers guidance on how to streamline both the RI/FS and the selection of a remedy for municipal landfills.

1.5 MODIFICATION OF PRELIMINARY REMEDIATION GOALS

The initial list of PRGs may need to be revised as new data become available during the RI/FS. Therefore, upon completion of the baseline risk assessment, it is important to review the media and chemicals of potential concern, future land use, and exposure assumptions originally identified at scoping. Chemicals may be added or dropped from the list, and risk-based PRGs may need to be recalculated using site-specific exposure factors. PRGs that are modified based on the results of the baseline risk assessment must still meet the

"threshold criteria" of: (1) protection of human health and the environment and (2) compliance with ARARs. However, the NCP also allows for modification of PRGs during final remedy selection based on the "balancing" and "modifying" criteria and factors relating to uncertainty, exposure, and technical feasibility.

Final remediation levels are not determined until the site remedy is ready to be selected; final remediation levels are then set out in the ROD. PRGs are refined into final remediation goals throughout the process leading up to remedy selection. The ROD itself, however, should include a statement of final clean-up levels based on these goals, as noted in NCP section 300.430(e)(2)(i)(A). In the ROD, it is preferable to use the term "remediation level" rather than "remediation goal" in order to make clear that the selected remedy establishes binding requirements.

1.6 DOCUMENTATION AND COMMUNICATION OF PRELIMINARY REMEDIATION GOALS

Clear and concise communication of risk-based PRGs among the risk assessor, the RPM, the ARARs coordinator, site engineers, analytical chemists, hydrogeologists, and others is important in the development of PRGs. The involvement of the RPM in the direction and development of risk-based PRGs is important to ensure that communication is facilitated and that the PRGs are used effectively in streamlining the RI/FS process.

Because PRGs are most useful during the RI/FS (e.g., for streamlining the consideration of remedial alternatives), it is important to communicate them to site engineers as soon as possible. A memorandum from either the site risk assessor or the RPM to the site engineers and others concerned with PRGs would be appropriate for transmitting the initial PRGs. A brief cover page could highlight key assumptions, as well as changes, if any, to the standard equations (i.e., those presented in this guidance). Following this brief discussion, the PRGs could be presented using a table similar to that in Section 3.4 of this guidance.

The RI/FS Guidance recommends that "chemical- and/or risk-based remedial objectives

associated with the alternative should be documented in the final RI/FS report to the extent possible." Therefore, the RI/FS report is a logical place to present PRGs that have been modified after the baseline risk assessment. A summary table such as the one developed in Section 3.4 of Part B could be incorporated into the RI/FS following the presentation of the baseline risk assessment. Along with the table, a discussion of issues of particular interest, such as assumptions used and the relationship between ARARs and risk-based PRGs at the site, could be included. Also, it is always appropriate to discuss how findings of the baseline risk assessment were incorporated into the calculation of PRGs.

1.7 ORGANIZATION OF DOCUMENT

The remainder of this guidance is organized into three additional chapters and two appendices. Chapter 2 discusses the initial identification of PRGs and provides guidance for modifying appropriate values during the RI/FS. Chapter 3 outlines equations that can be used to calculate risk-based PRGs for residential and commercial/industrial land uses. These equations are presented in both "reduced" format (i.e., incorporating certain default assumptions discussed in Chapter 2) and expanded format (i.e., with all variables included so that the user of this guidance can incorporate site-specific values). Particular considerations regarding radionuclides are provided in Chapter 4.

Appendix A supports several points made in Chapter 2 by providing illustrations of remedial alternatives where one or more chemicals "limit" remediation and, thus, represent a major portion of the residual risk. Appendix B lists equations for media-specific exposure pathways, enabling the risk assessor to derive site-specific equations that differ from those presented in Chapter 3.

Throughout Chapters 2, 3, and 4, case studies are presented that illustrate the process of determining PRGs. These case studies are contained in boxes with a shadow box appearance. Other types of boxed information (e.g., NCP quotes) is contained in boxes such as those in Chapter 1, which have thicker lines on the top and bottom than on the sides.

CHAPTER 2

IDENTIFICATION OF PRELIMINARY REMEDIATION GOALS

This chapter provides guidance on the initial identification of PRGs during the scoping phase of the RI/FS. As discussed in Chapter 1, medium-specific PRGs (ARAR-based and/or risk-based) should be identified during scoping for all chemicals of potential concern using readily available information. Sections are provided in this chapter on how to use this information to identify media and chemicals of potential concern, the most appropriate future land use, potential exposure pathways, toxicity information, potential ARARs, and risk-based PRGs. Finally, a section is provided on the modification of PRGs.

When using PRGs developed during scoping, the design engineers should understand that these may be modified significantly depending on information gathered about the site. The subsequent process of identifying key site contaminants, media, and other factors (i.e., during the baseline risk assessment) may require that the focus of the RI/FS be shifted (e.g., chemicals without ARARs may become more or less important). Thus, the design of remedial alternatives should remain flexible until the modified (i.e., more final) PRGs are available.

Prior to identifying PRGs during scoping, a conceptual site model should be developed (see the next box). Originally developed to aid in planning site activities (e.g., the RI/FS), the conceptual site model also contains information that is valuable for identifying PRGs. For example, it can be relied upon to identify which media and chemicals need PRGs. More information on developing and using a conceptual site model during the RI/FS process can be found in Chapter 2 of the RI/FS Guidance and Chapter 4 of RAGS/HHEM Part A.

To illustrate the process of calculating risk-based PRGs at the scoping stage of remediation, hypothetical CERCLA sites will be examined in boxes in appropriate sections throughout Chapters 2, 3, and 4. See the box on

---

> ### CONCEPTUAL SITE MODEL
>
> During project planning, the RPM gathers and analyzes available information and develops the conceptual site model (also called the conceptual evaluation model). This model is used to assess the nature and the extent of contamination. It also identifies potential contaminant sources, potential exposure pathways, and potential human and/or environmental receptors. Further, this model helps to identify data gaps and assists staff in developing strategies for data collection. Site history and PA/SI data generally are extremely useful sources of information for developing this model. The conceptual site model should include known and suspected sources of contamination, types of contaminants and affected media, known and potential routes of migration, and known or potential human and environmental receptors.

the next page for an introduction to the first site. (The radiation case study is addressed in Chapter 4.) The information (e.g., toxicity values) contained in these case studies is for illustration only, and should not be used for any other purpose. These case studies have been simplified (e.g., only ground water will be examined) so that the steps involved in developing risk-based PRGs can be readily discerned.

2.1 MEDIA OF CONCERN

During scoping, the first step in developing PRGs is to identify the media of potential concern. The conceptual site model should be very useful for this step. These media can be either:

- currently contaminated media to which individuals may be exposed or through which chemicals may be transported to potential receptors; or

---

- currently uncontaminated media that may become contaminated in the future due to contaminant transport.

Several important media often requiring direct remediation are ground water, surface water, soil, and sediment. Currently, only the first three of these media are discussed in this chapter and addressed by the equations provided in Chapters 3 and 4. If other media that may require the development of risk-based concentrations (e.g., sediments) are identified at scoping, appropriate equations for those media should be developed. Regional risk assessors should be consulted as early as possible to assist with this process.

2.2 CHEMICALS OF CONCERN

This step involves developing an initial list of chemicals for which PRGs need to be developed. Chapters 4 and 5 of RAGS/HHEM Part A provide important additional information on identifying chemicals of potential concern for a site and should be consulted prior to development of the conceptual site model, and PRGs at scoping.

Initially, the list of chemicals of potential concern should include any chemical reasonably expected to be of concern at the site based on what is known during scoping. For example, important chemicals previously detected at the site, based on the PA/SI, the conceptual site model, or other prior investigations, generally should be included. In addition, the list may include chemicals that the site history indicates are likely to be present in significant quantities, even though they may not yet be detected. Sources of this latter type of information include records of chemicals used or disposed at the facility, and interviews with current or former employees. The list also may include chemicals that are probable degradation products of site contaminants where these are determined to be potential contributors of significant risk. An environmental chemist should be consulted for assistance in determining the probable degradation products of potential site-related chemicals and their persistence under site conditions. Generally, the chemicals for which PRGs should be developed will correspond to the list of suspected site contaminants included in the sampling and analysis plan.

2.3 FUTURE LAND USE

This step involves identifying the most appropriate future land use for the site so that the appropriate exposure pathways, parameters, and equations (discussed in the next section) can be used to calculate risk-based PRGs. RAGS/HHEM Part A (Chapter 6) and an EPA Office of Solid Waste and Emergency Response (OSWER) directive on the role of the baseline risk assessment in remedy selection decisions (EPA 1991b) provide additional guidance on identifying future land use. The standard default equations provided in Chapter 3 of Part B only address residential and commercial/industrial land uses. If land uses other than these are to be assumed (e.g., recreational), then exposure pathways, parameters

and equations will need to be developed for the
others as well.

In general, residential areas should be assumed
to remain residential. Sites that are surrounded by
operating industrial facilities can be assumed to
remain industrial areas unless there is an
indication that this is not appropriate. Lacking
site-specific information (e.g., at scoping), it may
be appropriate to assume residential land use.
This assumption will generally lead to conservative
(i.e., lower concentration) risk-based PRGs. If not
enough site-specific information is readily available
at scoping to select one future land use over
another, it may be appropriate to develop a
separate set of risk-based PRGs for each possible
land use.

When waste will be managed onsite, land-use
assumptions and risk-based PRG development
become more complicated because the assumptions
for the site itself may be different from the land
use in the surrounding area. For example, if waste
is managed onsite in a residential area, the
risk-based PRGs for the ground water beneath the
site (or at the edge of the waste management unit)
may be based on residential exposures, but the
risk-based PRGs for the site soils may be based on
an industrial land use with some management or
institutional controls.

If a land-use assumption is used that is less
conservative (i.e., leads to higher risk-based
concentrations) than another, it generally will be
necessary to monitor the future uses of that site.

For example, if residential land use is not deemed
to be appropriate for a particular site because local
zoning laws prohibit residential development, any
changes in local zoning would need to be
monitored. Such considerations should be clearly
documented in the site's ROD.

2.4 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

Chemical-specific ARARs are evaluated as
PRGs because they are often readily available and
provide a preliminary indication about the goals
that a remedial action may have to attain. This
step involves identifying all readily available
chemical-specific potential ARARs for the
chemicals of potential concern (for each medium
and probable land use). Because at scoping it
often is uncertain which potential ARAR is the
most likely one to become the ARAR-based PRG,
all potential ARARs should be included in a
tabular summary (i.e., no potential ARAR should
be discarded). If there is doubt about whether a
value is a potential ARAR, and therefore whether
it could be used as a PRG, it should be included at
this stage.

This section summarizes the concept of
ARARs and identifies the major types of ARARs,
but provides only limited guidance on identifying
the most appropriate (likely) ARAR of all possible
ARARs to use as the chemical-specific PRG.
More detailed information about the identification
and evaluation of ARARs is available from two
important sources:

• the NCP (see specifically 55 Federal Register
8741-8766 for a description of ARARs, and

8712-8715 for using ARARs as PRGs; see also *53 Federal Register* 51394); and ,

- CERCLA Compliance Manuals (EPA 1988a and 1989a).

2.4.1 CHEMICAL-, LOCATION-, AND ACTION-SPECIFIC ARARs

The Agency has identified three general types of federal and state ARARs:

- chemical-specific, are usually health- or risk management-based numbers or methodologies that, when applied to site-specific conditions, result in the establishment of numerical values (e.g., chemical-specific concentrations in a given medium);

- location-specific, are restrictions placed upon the concentration of hazardous substances or the conduct of activities solely because they are in special locations (e.g., wetlands); and

- action-specific, are usually technology- or activity-based requirements or limitations on actions taken with respect to hazardous wastes.

This guidance primarily addresses only chemical-specific ARARs since it focuses on the identification of chemical-specific concentrations that represent target goals (e.g., PRGs) for a given medium.

2.4.2 SELECTION OF THE MOST LIKELY ARAR-BASED PRG FOR EACH CHEMICAL

This section briefly describes which, if any, of several potential ARAR values for a given chemical is generally selected as the most likely ARAR-based PRG (and therefore the most likely PRG at this point). Although the process for identifying the most likely ARAR-based PRG is specific to the medium, in general the process depends on two considerations: (1) the applicability of the ARAR to the site; and (2) the comparative stringency of the standards being evaluated. The previously cited documents should be carefully considered for specific recommendations on identifying ARARs.

Ground Water. SDWA maximum contaminant levels (MCLs), non-zero MCLGs, state drinking water standards, and federal water quality criteria

(FWQC) are common ARARs (and, therefore, potential PRGs) for ground water. Other types of laws, such as state anti-degradation laws, may be PRGs if they are accompanied by allowable concentrations of a chemical. (Although state anti-degradation laws that are expressed as qualitative standards may also be potential ARARs, they generally would not be considered PRGs.)

As detailed in the NCP (see next box), the first step in identifying ground-water PRGs is to determine whether the ground water is a current or potential source of drinking water. If the aquifer is a potential source of drinking water, then potential ARARs generally will include the federal non-zero MCLG, MCL, or state drinking water standard, and the most stringent (i.e., the lowest concentration) is identified as the most likely ARAR-based PRG.

NCP ON GROUND-WATER GOALS
(NCP Preamble;
55 Federal Register 8717, March 8, 1990)

"Ground water that is not currently a drinking water source but is potentially a drinking water source in the future would be protected to levels appropriate to its use as a drinking water source. Ground water that is not an actual or potential source of drinking water may not require remediation to a 10^{-4} to 10^{-6} level (except when necessary to address environmental concerns or allow for other beneficial uses; . . .)."

If the aquifer is not a potential source of drinking water, then MCLs, MCLGs, state drinking water requirements, or other health-based levels generally are not appropriate as PRGs. Instead, environmental considerations (i.e., effects on biological receptors) and prevention of plume expansion generally determine clean-up levels. If an aquifer that is not a potential source of drinking water is connected to an aquifer that is a drinking water source, it may be appropriate to use PRGs to set clean-up goals for the point of interconnection.

For chemicals without MCLs, state standards, or non-zero MCLGs, the FWQC may be potentially relevant and appropriate for ground water when that ground water discharges to surface water that is used for fishing or shellfishing.

Surface Water. FWQC and state water quality standards (WQS) are common ARARs for surface water. An important determination for identifying ARARs and other criteria as potential PRGs for surface water is the current designated and future expected use of the water body. Because surface water potentially could serve many uses (e.g., drinking and fishing), several ARARs may be identified as potential PRGs for a chemical, with each ARAR corresponding to an identified use. A state WQS is generally the most likely ARAR for surface water unless a federal standard is more stringent.

If surface water is a current or potential source of drinking water, MCLs, state drinking water standards, non-zero MCLGs, and FWQC are potential ARARs. The analysis to determine which of these drinking water standards is the most likely ARAR-based PRG is the same as that conducted for ground water. An FWQC based on ingestion of water and fish might be an ARAR for surface water used for drinking.

If the designated or future expected use of surface water is fishing or shellfishing, and the state has not promulgated a WQS, an FWQC should be considered as a potential ARAR. The particular FWQC (i.e., for water and fish ingestion or fish ingestion alone) selected as the potential ARAR depends on whether exposure from one or both of the routes is likely to occur and, therefore, on the designated use of the water body. If other uses of the water are designated (e.g., swimming), a state WQS may be available.

Soil. In general, chemical-specific ARARs may not be available for soil. Certain states, however, have promulgated or are about to promulgate soil standards that may be ARARs and thus may be appropriate to use as PRGs. In addition, several EPA policies may be appropriate to use in developing PRGs (e.g., see EPA 1990c for guidance on PCB clean-up levels).

2.5 EXPOSURE PATHWAYS, PARAMETERS, AND EQUATIONS

This step is generally conducted for each medium and land-use combination and involves identifying the most appropriate (1) exposure pathways and routes (e.g., residential ingestion of drinking water), (2) exposure parameters (e.g.,

2 liters/day of water ingested), and (3) equations (e.g., to incorporate intake). The equations include calculations of total intake from a given medium and are based on the identified exposure pathways and associated parameters. Information gathered in this step should be used to calculate risk-based PRGs using the default equations identified in Chapters 3 and 4. Site-specific equations can be derived if a different set of exposure pathways is identified for a particular medium; this option also is discussed in Chapters 3 and 4.

When risk-based concentrations are developed during scoping, readily available site-specific information may be adequate to identify and develop the exposure pathways, parameters, and equations (e.g., readily available information may indicate that the exposure duration should be 40 years instead of the standard default of 30 years). In the absence of readily available site-specific information, the standard default information in Chapters 3 and 4 generally should be used for the development of risk-based PRGs.

Exhibit 2-1 lists a number of the potential exposure pathways that might be present at a CERCLA site. The exposure pathways included in the medium-specific standard default equations (see Chapters 3 and 4) are italicized in this exhibit. Note that Chapters 3 and 4 may not address all of the exposure pathways of possible importance at a given CERCLA site. For example, the consumption of ground water that continues to be contaminated by soil leachate is not addressed. Guidance on goal-setting to address this exposure pathway is currently under development by EPA. In addition, the standard default equations do not address pathways such as plant and animal uptake of contaminants from soil with subsequent human ingestion. Under certain circumstances, these or other exposure pathways may present significant risks to human health. The standard default information, however, does address the quantifiable exposure pathways that are often significant contributors of risk for a particular medium and land use.

Chapters 3 and 4 show how exposures from several pathways are addressed in a single equation for a medium. For example, in the equation for ground water and surface water under the residential land-use assumption, the coefficients incorporate default parameter values for ingestion of drinking water and inhalation of volatiles during

EXHIBIT 2-1

TYPICAL EXPOSURE PATHWAYS BY MEDIUM
FOR RESIDENTIAL AND COMMERCIAL/INDUSTRIAL LAND USES[a,b]

Medium	Exposure Pathways, Assuming:	
	Residential Land Use	Commercial/Industrial Land Use
Ground Water	*Ingestion from drinking*	Ingestion from drinking[d]
	Inhalation of volatiles	Inhalation of volatiles
	Dermal absorption from bathing	Dermal absorption
	Immersion - external[c]	
Surface Water	*Ingestion from drinking*	Ingestion from drinking[d]
	Inhalation of volatiles	Inhalation of volatiles
	Dermal absorption from bathing	Dermal absorption
	Ingestion during swimming	
	Ingestion of contaminated fish	
	Immersion - external[c]	
Soil	*Ingestion*	*Ingestion*
	Inhalation of particulates	*Inhalation of particulates*
	Inhalation of volatiles	*Inhalation of volatiles*
	Direct external exposure[c]	*Direct external exposure[c]*
	Exposure to ground water contaminated by soil leachate	Exposure to ground water contaminated by soil leachate
	Ingestion via plant uptake	Inhalation of particulates from trucks and heavy equipment
	Dermal absorption from gardening	

[a] Lists of land uses, media, and exposure pathways are not comprehensive.

[b] Exposure pathways included in RAGS/HHEM Part B standard default equations (Chapters 3 and 4) are italicized.

[c] Applies to radionuclides only.

[d] Because the NCP encourages protection of ground water to maximize its beneficial use, risk-based PRGs generally should be based on residential exposures once ground water is determined to be suitable for drinking. Similarly, when surface water will be used for drinking, general standards (e.g., ARARs) are to be achieved that define levels protective for the population at large, not simply worker populations. Residential exposure scenarios should guide risk-based PRG development for ingestion and other uses of potable water.

household water use. Full details of parameters used to develop each equation and a summary of the "reduced" standard default equations are provided in the text of these chapters.

Certain modifications of the default equations may be desirable or necessary. For example, if an exposure pathway addressed by an equation in Chapter 3 seems inappropriate for the site (e.g., because the water contains no volatiles and, therefore, inhalation of volatiles is irrelevant), or if information needed for a pathway (e.g., a chemical-specific inhalation slope factor [see Section 2.6]) is not readily available or derivable, then that pathway can be disregarded at this stage.

The decision about whether the risk assessor should collect site-specific human exposure pathway information (e.g., exposure frequency, duration, or intake rate data) is very important. There will frequently be methods available to gather such information, some of which are more expensive and elaborate than others. Determining whether the resulting data are reasonably representative of populations in the surrounding area, however, is often difficult. Collecting data by surveying those individuals most convenient or accessible to RPMs or risk assessors may not present a complete population exposure picture. In fact, poorly planned data gathering efforts may complicate the assessment process. For example, those surveyed may come to believe that their contributions will play a more meaningful role in the risk assessment than that planned by the risk assessors; this can result in significant demands on the risk assessor's time.

Before such data collection has begun, the risk assessor should determine, with the aid of screening analyses, what benefits are likely to result. Collection of the exposure data discussed in this section generally should not be attempted unless significant differences are likely to result in final reasonable maximum exposure (RME) risk estimates. If data collection is warranted, systematic and well-considered efforts that minimize biases in results should be undertaken. Estimates of future exposures are likely to rely heavily on conservative exposure assumptions. By definition, these assumptions will be unaffected by even the most extensive efforts to characterize current population activity.

At this stage, the risk assessor, site engineer, and RPM should discuss information concerning the absence or presence of important exposure pathways, because remediation goals should be designed for specific areas of the site that a particular remedy must address, and exposures expected for one area of the site may differ significantly from those expected in another area.

2.5.1 GROUND WATER/SURFACE WATER

The residential land-use default equations presented in Chapters 3 and 4 for ground water or surface water are based on ingestion of drinking water and inhalation of volatile (vapor phase) chemicals originating from the household water supply (e.g., during dish washing, clothes laundering, and showering).

Ingestion of drinking water is an appropriate pathway for all chemicals with an oral cancer slope factor or an oral chronic reference dose. For the purposes of this guidance, however, inhalation of volatile chemicals from water is considered routinely only for chemicals with a Henry's Law constant of 1×10^{-5} atm-m^3/mole or greater and with a molecular weight of less than 200 g/mole. Before determining inhalation toxicity values for a specific chemical (Section 2.6), it should be confirmed that the Henry's Law constant and molecular weight are in the appropriate range for inclusion in the inhalation pathway for water.

Default equations addressing industrial use of ground water are not presented. Because the NCP encourages protection of ground water to its maximum beneficial use, once ground water is determined to be suitable for drinking, risk-based PRGs generally should be based on residential exposures. Even if a site is located in an industrial area, the ground water underlying a site in an industrial area may be used as a drinking water source for residents several miles away due to complex geological interconnections.

2.5.2 SOIL

The residential land-use standard default equations for the soil pathway are based on exposure pathways of ingestion of chemicals in soil or dust. The industrial land-use equations are based on three exposure pathways: ingestion of soil and dust, inhalation of particulates, and inhalation of volatiles. Again, for the purposes of this guidance, inhalation of volatile chemicals is relevant only for chemicals with a Henry's Law constant of 1×10^{-5} atm-m^3/mole or greater and

with a molecular weight of less than 200 g/mole. For the inhalation pathways, in addition to toxicity information, several chemical- and site-specific values are needed. These values include molecular diffusivity, Henry's Law constant, organic carbon partition coefficient, and soil moisture content (see Chapter 3 for details).

```
CASE STUDY: IDENTIFY EXPOSURE
      PATHWAYS, PARAMETERS,
        AND EQUATIONS

   For the potential residential land use
identified at the XYZ Co. site, the contaminated
ground water (one of several media of potential
concern) appears to be an important source of
future domestic water. Because site-specific
information is not initially available to develop
specific exposure pathways, parameters, and
equations, the standard default assumptions and
equations provided in Chapter 3 will be used to
calculate risk-based PRGs. Exposure pathways
of concern for ground water, therefore, are
assumed to be ingestion of ground water as
drinking water and inhalation of volatiles in
ground water during household use.
```

2.6 TOXICITY INFORMATION

This step involves identifying readily available toxicity values for all of the chemicals of potential concern for given exposure pathways so that the appropriate slope factors (SFs; for carcinogenic effects) and reference doses (RfDs; for noncarcinogenic effects) are identified or derived for use in the site-specific equations or the standard default equations. Therefore, Chapter 7 of RAGS/HHEM Part A should be reviewed carefully before proceeding with this step.

The hierarchy for obtaining toxicity values for risk-based PRGs is essentially the same as that used in the baseline risk assessment. Briefly, Integrated Risk Information System (IRIS) is the primary source for toxicity information; if no verified toxicity value is available through IRIS, then Health Effects Assessment Summary Tables (HEAST) is the next preferred source. When the development of a toxicity value is required (and appropriate data are available), consultation with the Superfund Health Risk Assessment Technical Support Center is warranted. EPA staff can contact the Center by calling FTS-684-7300

(513-569-7300) or by FAX at FTS-684-7159 (513-569-7159). Others must fax to the above number or write to:

    Superfund Health Risk Technical Support
    Center
    Environmental Criteria and Assessment Office
    U.S. Environmental Protection Agency
    Mail Stop 114
    26 West Martin Luther King Drive
    Cincinnati, Ohio 45268

Other toxicity information that should be obtained includes EPA's weight-of-evidence classification for carcinogens (e.g., A, B1) and the source of the information (e.g., IRIS, HEAST).

Note that throughout this document, the term hazard index (HI) is used to refer to the risk level associated with noncarcinogenic effects. An HI is the sum of two or more hazard quotients (HQs). An HQ is the ratio of an exposure level of a single substance to the RfD for that substance. Because RfDs are generally exposure pathway-specific (e.g., inhalation RfD), the HQ is a single substance/ single exposure pathway ratio. An HI, on the other hand, is usually either a single substance/ multiple exposure pathway ratio, a multiple substance/single exposure pathway ratio, or a multiple substance/multiple exposure pathway ratio. In this document, however, only one exposure pathway is included in the default equation for some land-use and medium combinations (e.g., residential soil). In order to remain consistent, the term HI has been used throughout RAGS/HHEM Part B, even though for such a pathway, the term HQ could apply.

2.7 TARGET RISK LEVELS

This step involves identifying target risk concentrations for chemicals of potential concern. The standard default equations presented in Chapters 3 and 4 are based on the following target risk levels for carcinogenic and noncarcinogenic effects.

* For carcinogenic effects, a concentration is calculated that corresponds to a 10^{-6} incremental risk of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen from all significant exposure pathways for a given medium.

- For noncarcinogenic effects, a concentration is calculated that corresponds to an HI of 1, which is the level of exposure to a chemical from all significant exposure pathways in a given medium below which it is unlikely for even sensitive populations to experience adverse health effects.

At scoping, it generally is appropriate to use the standard default target risk levels described above and discussed in the NCP. That is, an appropriate point of departure for remediation of carcinogenic risk is a concentration that corresponds to a risk of 10^{-6} for one chemical in a particular medium. For noncarcinogenic effects, the NCP does not specify a range, but it generally is appropriate to assume an HI equal to 1.

2.8 MODIFICATION OF PRELIMINARY REMEDIATION GOALS

Upon completion of the baseline risk assessment (or as soon as data are available), it is important to review the future land use, exposure assumptions, and the media and chemicals of potential concern originally identified at scoping, and determine whether PRGs need to be modified. Modification may involve adding or subtracting

chemicals of concern, media, and pathways or revising individual chemical-specific goals.

2.8.1 REVIEW OF ASSUMPTIONS

Media of Concern. As a guide to determining the media and chemicals of potential concern, the OSWER directive *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions* (EPA 1991c) indicates that action is generally warranted at a site when the cumulative carcinogenic risk is greater than 10^{-4} or the cumulative noncarcinogenic HI exceeds 1 based on RME assumptions. Thus, where the baseline risk assessment indicates that either the cumulative current or future risk associated with a medium is greater than 10^{-4} or that the HI is greater than 1, that medium presents a concern, and it generally is appropriate to maintain risk-based PRGs for contaminants in that medium or develop risk-based PRGs for additional media where PRGs are not clearly defined by ARARs.

When the cumulative current or future baseline cancer risk for a medium is within the range of 10^{-6} to 10^{-4}, a decision about whether or not to take action is a site-specific determination. Generally, risk-based PRGs are not needed for any chemicals in a medium with a cumulative cancer risk of less than 10^{-6}, where an HI is less than or

equal to 1, or where the PRGs are clearly defined by ARARs. However, there may be cases where a medium appears to meet the protectiveness criterion but contributes to the contamination of another medium (e.g., soil contributing to ground-water contamination). In these cases, it may be appropriate to modify existing or develop new risk-based PRGs for chemicals of concern in the first medium, assuming that fate and transport models can adequately predict the impacts of concern on other media. EPA is presently developing guidance on quantifying the impact of soil contamination on underlying aquifers.

Chemicals of Concern. As with the initial media of potential concern, the initial list of specific chemicals of potential concern in a given medium may need to be modified to reflect increased information from the RI/FS concerning the importance of the chemicals to the overall site risk. Chemicals detected during the RI/FS that were not anticipated during scoping should be considered for addition to the list of chemicals of potential concern; chemicals anticipated during scoping that were not detected during the RI/FS should be deleted from the list. Ultimately, the identity and number of contaminants that may require risk-based PRGs depends both on the results of the baseline risk assessment and the extent of action required, given site-specific circumstances.

Following the baseline risk assessment, any chemical that has an associated cancer risk (current or future) within a medium of greater than 10^{-6} or an HI of greater than 1 should remain on the list of chemicals of potential concern for that medium. Likewise, chemicals that present cancer risks of less than 10^{-6} generally should not be retained on the list unless there are significant concerns about multiple contaminants and pathways.

Land Use. After the RI/FS, one future land use can usually be selected based on the results of the baseline risk assessment and discussions with the RPM. In many cases, this land use will be the same as the land use identified at scoping. In other cases, however, additional information from the baseline risk assessment that was not available at scoping may suggest modifying the initial land-use and exposure assumptions. A qualitative assessment should be made — and should be available from the baseline risk assessment — of

the likelihood that the assumed future land use will occur.

Exposure Pathways, Parameters, and Equations. For exposure pathways, this process of modifying PRGs consists of adding or deleting exposure pathways from the medium-specific equations in Chapters 3 and 4 to ensure that the equation accounts for all significant exposure pathways associated with that medium at the site. For example, the baseline risk assessment may indicate that dermal exposure to contaminants in soil is a significant contributor to site risk. In this case, the risk-based PRGs may be modified by adding equations for dermal exposure. EPA policy on assessing this pathway is currently under development; the risk assessor should consult the Superfund Health Risk Technical Support Center (FTS-684-7300 or 513-569-7300) to determine the current status of guidance. Likewise, when appropriate data (e.g., on exposure frequency and duration) have been collected during the RI/FS, site-specific values can be substituted for the default values in the medium-specific equations.

2.8.2 IDENTIFICATION OF UNCERTAINTIES

The uncertainty assessment for PRGs can serve as an important basis for recommending further modifications to the PRGs prior to setting final remediation goals. It also can be used during the post-remedy assessment (see Section 2.8.4) to identify areas needing particular attention.

Risk-based PRGs are associated with varied levels of uncertainty, depending on many factors (e.g., confidence that anticipated future land use is correct). To place risk-based PRGs that have been developed for a site in proper perspective, an assessment of the uncertainties associated with the concentrations should be conducted. This assessment is similar to the uncertainty assessment conducted during the baseline risk assessment (see RAGS/HHEM Part A, especially Chapters 6, 7, and 8). In fact, much of the uncertainty assessment conducted for a site's baseline risk assessment will be directly applicable to the uncertainty assessment of the risk-based PRGs.

In general, each component of risk-based PRGs discussed in this chapter — from media of potential concern to target risk level — should be examined, and the major areas of uncertainty highlighted. For example, the uncertainty

associated with the selected future land use should be discussed. Furthermore, the accuracy of the technical models used (e.g., for volatilization of contaminants from soil) to reflect site-specific conditions (present and future) should be discussed. If site-specific exposure assumptions have been made, it is particularly important to document the data supporting those assumptions and to assess their relevance for potentially exposed populations.

As the chemical- and medium-specific PRGs are developed, many assumptions regarding the RME individual(s) are incorporated. Although PRGs are believed to be fully protective for the RME individual(s), the proximity of other nearby sources of exposure (e.g., other CERCLA sites, RCRA facilities, naturally occurring background contamination) and/or the existence of the same contaminants in multiple media or of multiple chemicals affecting the same population(s), may lead to a situation where, even after attainment of all PRGs, protectiveness is not clearly achieved (e.g., cumulative risks may fall outside the risk range). The more likely it is that multiple contaminants, pathways, operable units, or other sources of toxicants will affect the RME individual(s), the more likely it will be that protectiveness is not achieved. This likelihood should be addressed when identifying uncertainties.

2.8.3 OTHER CONSIDERATIONS IN MODIFYING PRGs

The NCP preamble and rule state that factors related to exposure, technical limitations, and uncertainty should be considered when modifying PRGs (see next two boxes) and setting final remediation levels.

While the final remedial action objectives must satisfy the original "threshold criteria" of protection of human health and the environment and compliance with ARARs, the factors in the "balancing and modifying criteria" (listed in Section 1.3.2) also are considered in the detailed analysis for choosing among remedial alternatives. In cases where the alternative that represents the best balance of factors is not able to attain cancer risks within the risk range or an HI of 1, institutional controls may be used to supplement treatment and/or containment-based remedial action to ensure protection of human health and the environment.

NCP PREAMBLE: EXPOSURE, TECHNICAL AND UNCERTAINTY FACTORS
(55 *Federal Register* 8717, March 8, 1990)

"Preliminary remediation goals ... may be revised ... based on the consideration of appropriate factors including, but not limited to: exposure factors, uncertainty factors, and technical factors. Included under exposure factors are: cumulative effect of multiple contaminants, the potential for human exposure from other pathways at the site, population sensitivities, potential impacts on environmental receptors, and cross-media impacts of alternatives. Factors related to uncertainty may include: the reliability of alternatives, the weight of scientific evidence concerning exposures and individual and cumulative health effects, and the reliability of exposure data. Technical factors may include: detection/quantification limits for contaminants, technical limitations to remediation, the ability to monitor and control movement of contaminants, and background levels of contaminants. The final selection of the appropriate risk level is made when the remedy is selected based on the balancing of criteria...."

NCP RULE: EXPOSURE, TECHNICAL AND UNCERTAINTY FACTORS
(40 CFR 300.430(e)(2)(i))

"(i)...Remediation goals...shall be developed by considering the following:

"(A) Applicable or relevant and appropriate requirements...and the following factors:

"(1) For systemic toxicants, acceptable exposure levels...;

"(2) For known or suspected carcinogens, acceptable exposure levels...;

"(3) Factors related to technical limitations such as detection/quantification limits for contaminants;

"(4) Factors related to uncertainty; and

"(5) Other pertinent information."

Note that in the absence of ARARs, the 10^{-6} cancer risk "point of departure" is used as a starting point for analysis of remedial alternatives, which reflects EPA's preference for managing risks at the more protective end of the risk range, other things being equal. Use of "point of departure" target risks in this guidance does not reflect a presumption that the final remedial action should attain such goals. (See NCP preamble, 55 *Federal Register* 8718-9.)

2.8.4   POST-REMEDY ASSESSMENT

To ensure that protective conditions exist after the remedy achieves all individual remediation levels set out in the ROD, there generally will be a site-wide evaluation conducted following completion of a site's final operable unit (e.g., during the five-year review). This site-wide evaluation should adequately characterize the residual contaminant levels and ensure that the post-remedy cumulative site risk is protective. More detailed guidance on the post-remedy assessment of site "protectiveness" is currently under development by EPA.

CHAPTER 3

CALCULATION OF RISK-BASED PRELIMINARY REMEDIATION GOALS

This chapter presents standardized exposure parameters, the derivation of risk equations, and the corresponding "reduced" equations, for calculating risk-based PRGs at scoping for the media and land-use assumptions discussed in Chapter 2 (i.e., ground water, surface water, and soil for residential land use, and soil for commercial/industrial land use). Both carcinogenic and noncarcinogenic effects are addressed. Standardized default exposure parameters consistent with OSWER Directive 9285.6-03 (EPA 1991b) are used in this chapter; where default parameters are not available in that guidance, the references used are cited. If other media requiring risk-based PRGs are identified during the RI/FS, or other exposure parameters or land uses are assumed, then appropriate equations will need to be modified or new ones developed.

Risk-based equations have been derived in order to reflect the potential risk from exposure to a chemical, given a specific pathway, medium, and land-use combination. By setting the total risk for carcinogenic effects at a target risk level of 10^{-6} (the NCP's point of departure for analysis of remedial alternatives), it is possible to solve for the concentration term (i.e., the risk-based PRG). The total risk for noncarcinogenic effects is set at an HI of 1 for each chemical in a particular medium. Full equations with pathway-specific default exposure factors are presented in boxes with uniformly thin borders. Reduced equations are presented in the standard boxes (i.e., thicker top and bottom borders). At the end of this chapter, the case study that began in Chapter 2 is concluded (by showing how to calculate and present risk-based PRGs).

In general, the equations described in this chapter are sufficient for calculating the risk-based PRGs at the scoping stage of the RI/FS. Note, however, that these equations are based on standard default assumptions that may or may not reflect site-specific conditions. When risk-based PRGs are to be calculated based on site-specific

conditions, the risk assessor should modify the full equations, and/or develop additional ones. Risk equations for individual exposure pathways for a given medium are presented in Appendix B of this document, and may be used to develop and/or modify the full equations. (See the introduction to Appendix B for more detailed instructions.)

Before examining the calculation of risk-based PRGs, several important points should be noted:

- Use of toxicity values in the equations as written currently assumes 100 percent absorption effeciency. That is, for the sake of simplicity at scoping, it is assumed that the dose administered to test animals in toxicity studies on which toxicity values are based was fully absorbed. This assumption may need to be revised in cases where toxicity values based on route-to-route extrapolation are used, or there are significant differences in absorption likely between contaminants in site media and the contaminants in the vehicle used in the toxicity study. Chapter 7 and Appendix A in RAGS/HHEM Part A (EPA 1989d) provide additional details on this point.

- The risk-based PRGs should contain at most two significant figures even though some of the parameters used in the reduced equations carry additional significant figures.

- The equations presented in this chapter calculate risk-based concentrations using inhalation reference doses (RfD_is) and inhalation slope factors (SF_is). If only the reference concentration (RfC) and/or inhalation unit risk are available for a particular compound in IRIS, conversion to an RfD_i and/or SF_i will be necessary. Many converted toxicity values are available in HEAST.

- All standard equations presented here incorporate pathway-specific default exposure

factors that generally reflect RME conditions. As detailed in Chapter 8 of RAGS/HHEM Part A (in the discussion on combining pathway risks [Section 8.3]), RME risks from one pathway should be combined with RME risks from another pathway only where there is good reason. Typically, RME from one pathway is not likely to occur with RME from another (unless there is a strong logical dependent relationship between exposures from the two pathways). If risk-based concentrations are developed for both the water and the soil pathways, the risk assessor ultimately may need to adjust exposure assumptions from one pathway (i.e., the one with the lower RME) to less conservative (more typical) values.

3.1   RESIDENTIAL LAND USE

3.1.1   GROUND WATER OR SURFACE WATER

Under residential land use, risk from surface water or ground-water contaminants is assumed to be due primarily to direct ingestion and to inhalation of volatiles from household water use. Therefore, only these exposure pathways are considered in this section. Additional exposure pathways (e.g., dermal absorption) are possible and may be significant at some sites for some contaminants, while perhaps only one exposure pathway (e.g., direct ingestion of water only) may be relevant at others. In any case, the risk-based PRG for each chemical should be calculated by considering all of the relevant exposure pathways.

In the case illustrated here, risks from two exposure pathways from ground water or surface water are combined, and the risk-based concentration is derived to be protective for exposures from both pathways. Default risk from ground water or surface water would be calculated as follows ("total" risk, as used below, refers to the combined risk for a single chemical from all exposure pathways for a given medium):

| Total risk from water | = | Risk from ingestion of water (adult) | + | Risk from inhalation of volatiles from household water (adult) |

At scoping, risk from indoor inhalation of volatiles is assumed to be relevant only for chemicals that easily volatilize. Thus, the risk

equation incorporates a water-air concentration relationship that is applicable only to chemicals with a Henry's Law constant of greater than 1 x 10^{-5} atm-m^3/mole and a molecular weight of less than 200 g/mole. These criteria are not used to screen out chemicals that are not of potential concern for this exposure pathway but only to identify those that generally should be considered for the inhalation pathway when developing risk-based PRGs early in the process. Chemicals that do not meet these criteria may pose significant site risks (and require risk-based goals) through volatiles inhalation. The ultimate decision regarding which contaminants should be considered in the FS must be made on a site-specific basis following completion of the baseline risk assessment.

Based primarily on experimental data on the volatilization of radon from household uses of water, Andelman (1990) derived an equation that defines the relationship between the concentration of a contaminant in household water and the average concentration of the volatilized contaminant in air. In the derivation, all uses of household water were considered (e.g., showering, laundering, dish washing). The equation uses a default "volatilization" constant (K) upper-bound value of 0.0005 x 1000 L/m^3. (The 1000 L/m^3 conversion factor is incorporated into the equation so that the resulting air concentration is expressed in mg/m^3.) Certain assumptions were made in deriving the default constant K (Andelman 1990). For example, it is assumed that the volume of water used in a residence for a family of four is 720 L/day, the volume of the dwelling is 150,000 L and the air exchange rate is 0.25 m^3/hr. Furthermore, it is assumed that the average transfer efficiency weighted by water use is 50 percent (i.e., half of the concentration of each chemical in water will be transfered into air by all water uses [the range extends from 30% for toilets to 90% for dishwashers]). See the Andelman paper for further details.

Concentrations Based on Carcinogenic Effects. Total risk for carcinogenic effects of certain volatile chemicals would be calculated by combining the appropriate inhalation and oral SFs with the two intakes from water:

| Total risk | = | SF$_o$ x | Intake from ingestion of water | + | SF$_i$ x | Intake from inhalation of volatiles from water |

Adding appropriate parameters, and then rearranging the equation to solve for concentration, results in Equation (1).

Equation (1') on the next page is the reduced version of Equation (1) using the standard default parameters, and is used to calculate the risk-based PRG at a prespecified cancer risk level of 10^{-6}. It combines the toxicity information of a chemical with standard default exposure parameters for residential land use to generate the concentration of that chemical that corresponds to a 10^{-6} carcinogenic risk level due to that chemical. If either the SF_o or SF_i in Equation (1') is not available for a particular chemical, the term containing that variable in the equation can be ignored or equated to zero (e.g., for a chemical that does not have SF_i, the term $7.5(SF_i)$ in Equation (1') is ignored). If any of the default parameter values are changed to reflect site-specific conditions, the reduced equation cannot be used.

RESIDENTIAL WATER — CARCINOGENIC EFFECTS

$$TR = \frac{SF_o \times C \times IR_w \times EF \times ED}{BW \times AT \times 365 \text{ days/yr}} + \frac{SF_i \times C \times K \times IR_a \times EF \times ED}{BW \times AT \times 365 \text{ days/yr}}$$

$$= \frac{EF \times ED \times C \times [(SF_o \times IR_w) + (SF_i \times K \times IR_a)]}{BW \times AT \times 365 \text{ days/yr}}$$

$$C \text{ (mg/L; risk-based)} = \frac{TR \times BW \times AT \times 365 \text{ days/yr}}{EF \times ED \times [(SF_i \times K \times IR_a) + (SF_o \times IR_w)]} \qquad (1)$$

where:

Parameters	Definition (units)	Default Value
C	chemical concentration in water (mg/L)	—
TR	target excess individual lifetime cancer risk (unitless)	10^{-6}
SF_i	inhalation cancer slope factor ((mg/kg-day)$^{-1}$)	chemical-specific
SF_o	oral cancer slope factor ((mg/kg-day)$^{-1}$)	chemical-specific
BW	adult body weight (kg)	70 kg
AT	averaging time (yr)	70 yr
EF	exposure frequency (days/yr)	350 days/yr
ED	exposure duration (yr)	30 yr
IR_a	daily indoor inhalation rate (m³/day)	15 m³/day
IR_w	daily water ingestion rate (L/day)	2 L/day
K	volatilization factor (unitless)	0.0005 x 1000 L/m³ (Andelman 1990)

REDUCED EQUATION: RESIDENTIAL WATER — CARCINOGENIC EFFECTS

$$\text{Risk-based PRG} = \frac{1.7 \times 10^{-4}}{2(SF_o) + 7.5(SF_i)} \qquad (1')$$
$$(\text{mg/L; TR} = 10^{-6})$$

where:

SF_o = oral slope factor in (mg/kg-day)$^{-1}$

SF_i = inhalation slope factor in (mg/kg-day)$^{-1}$

Concentrations Based on Noncarcinogenic Effects. Total HI would be calculated by combining the appropriate oral and inhalation RfDs with the two intakes from water:

$$HI = \frac{\text{Intake from oral ingestion}}{RfD_o}$$

$$+ \frac{\text{Intake from inhalation}}{RfD_i}$$

Adding appropriate parameters, and then rearranging the equation to solve for concentration, results in Equation (2).

Equation (2') on the next page is the reduced version of Equation (2) using the standard default parameters, and is used to calculate the risk-based PRG at a prespecified HI of 1. It combines the toxicity information of a chemical with standard exposure parameters for residential land use to generate the concentration of that chemical that corresponds to an HI of 1. If either the RfD_o or RfD_i in Equation (2') is not available for a particular chemical, the term containing that variable in the equation can be ignored or equated to zero (e.g., for a chemical that does not have RfD_i, the term $7.5/RfD_i$ in Equations (2') is ignored).

RESIDENTIAL WATER — NONCARCINOGENIC EFFECTS

$$THI = \frac{C \times IR_a \times EF \times ED}{RfD_o \times BW \times AT \times 365 \text{ days/yr}} + \frac{C \times K \times IR_a \times EF \times ED}{RfD_i \times BW \times AT \times 365 \text{ days/yr}}$$

$$= \frac{EF \times ED \times C \times [(1/RfD_o \times IR_w) + (1/RfD_i \times K \times IR_a)]}{BW \times AT \times 365 \text{ days/yr}}$$

$$C \text{ (mg/L; risk-based)} = \frac{THI \times BW \times AT \times 365 \text{ days/yr}}{EF \times ED \times [(1/RfD_i \times K \times IR_a) + (1/RfD_o \times IR_w)]} \qquad (2)$$

where:

Parameters	Definition	Default Value
C	chemical concentration in water (mg/L)	—
THI	target hazard index (unitless)	1
RfD_o	oral chronic reference dose (mg/kg-day)	chemical-specific
RfD_i	inhalation chronic reference dose (mg/kg-day)	chemical-specific
BW	adult body weight (kg)	70 kg
AT	averaging time (yr)	30 yr (for noncarcinogens, equal to ED)
EF	exposure frequency (days/yr)	350 days/yr
ED	exposure duration (yr)	30 yr
IR_a	daily indoor inhalation rate (m³/day)	15 m³/day
IR_w	daily water ingestion rate (L/day)	2 L/day
K	volatilization factor (unitless)	0.0005 x 1000 L/m³ (Andelman 1990)

REDUCED EQUATION: RESIDENTIAL WATER — NONCARCINOGENIC EFFECTS

$$\text{Risk-based PRG (mg/L; THI = 1)} = \frac{73}{[7.5/RfD_i + 2/RfD_o]} \qquad (2')$$

where:

RfD_o = oral chronic reference dose in mg/kg-day

RfD_i = inhalation chronic reference dose in mg/kg-day

3.1.2 SOIL

Under residential land use, risk of the contaminant from soil is assumed to be due to direct ingestion of soil only.

Total risk from soil = Risk from ingestion of soil (child to adult)

Because the soil ingestion rate is different for children and adults, the risk due to direct ingestion of soil is calculated using an age-adjusted ingestion factor. The age-adjusted soil ingestion factor ($IF_{soil/adj}$) takes into account the difference in daily soil ingestion rates, body weights, and exposure durations for two exposure groups — children of one to six years and others of seven to 31 years. Exposure frequency (EF) is assumed to be identical for the two exposure groups. For convenience, this factor is calculated separately as a time-weighted soil intake, normalized to body weight, that can then be substituted in the total intake equation. Calculated in this manner, the factor leads to a more protective risk-based concentration compared to an adult-only assumption. Note that the ingestion factor is in units of mg-yr/kg-day, and therefore is not directly comparable to daily soil intake rate in units of mg/kg-day. See the box containing Equation (3) for the calculation of this factor.

Additional exposure pathways (e.g., inhalation of particulates, inhalation of volatiles, ingestion of foodcrops contaminated through airborne particulate deposits, consumption of ground water contaminated by soil leachate) are possible at some sites. The risk assessor should evaluate whether inhalation or other exposure pathways are significant at the site. Generally, for many undisturbed sites with vegetative cover such as those found in areas of residential land use, air pathways are relatively minor contributors of risk. Greater concern for baseline risk via air pathways exists under commercial/industrial land-use assumptions, given the increased activity levels likely (see Section 3.2.2). Air pathway risks also tend to be major concerns during remedial action (see RAGS/HHEM Part C). If these other pathways are known to be significant at scoping, Appendix B and/or other information should be used to develop site-specific equations for the risk-based PRGs.

Concentrations Based on Carcinogenic Effects. Total risk for carcinogenic effects would be calculated by combining the appropriate oral SF with the intake from soil:

Total risk = SF_o x Intake from ingestion of soil

Adding appropriate parameters, and then rearranging the equation to solve for concentration, results in Equation (4).

Equation (4') below is the reduced version of Equation (4) using the standard default parameters, and is used to calculate the risk-based PRG at a prespecified cancer risk level of 10^{-6}. It combines the toxicity information of a chemical with standard exposure parameters for residential land use to generate the concentration of that chemical that corresponds to a 10^{-6} carcinogenic risk level due to that chemical.

AGE-ADJUSTED SOIL INGESTION FACTOR

$$IF_{soil/adj} \text{ (mg-yr/kg-day)} = \frac{IR_{soil\,age1-6} \times ED_{age1-6}}{BW_{age1-6}} + \frac{IR_{soil\,age7-31} \times ED_{age7-31}}{BW_{age7-31}} \quad (3)$$

Parameter	Definition	Default Value
$IF_{soil/adj}$	age-adjusted soil ingestion factor (mg-yr/kg-day)	114 mg-yr/kg-day
BW_{age1-6}	average body weight from ages 1-6 (kg)	15 kg
$BW_{age7-31}$	average body weight from ages 7-31 (kg)	70 kg
ED_{age1-6}	exposure duration during ages 1-6 (yr)	6 yr
$ED_{age7-31}$	exposure duration during ages 7-31 (yr)	24 yr
$IR_{soil\,age1-6}$	ingestion rate of soil age 1 to 6 (mg/day)	200 mg/day
$IR_{soil\,age7-31}$	ingestion rate of soil all other ages (mg/day)	100 mg/day

---

```
                    RESIDENTIAL SOIL — CARCINOGENIC EFFECTS

TR      =       SF_o x  C x 10^{-6} kg/mg x EF x IF_{soil/adj}
                        AT x 365 days/yr

C (mg/kg; risk-    =         TR x AT x 365 days/year                        (4)
based)                   SF_o x 10^{-6} kg/mg x EF x IF_{soil/adj}

where:

Parameters      Definition (units)                                  Default Value

C               chemical concentration in soil (mg/kg)              —
TR              target excess individual lifetime cancer risk (unitless)   10^{-6}
SF_o            oral cancer slope factor ((mg/kg-day)^{-1})         chemical-specific
AT              averaging time (yr)                                 70 yr
EF              exposure frequency (days/yr)                        350 days/yr
IF_{soil/adj}   age-adjusted ingestion factor (mg-yr/kg-day)        114 mg-yr/kg-day (see Equation (3))
```

```
            REDUCED EQUATION:  RESIDENTIAL SOIL — CARCINOGENIC EFFECTS

Risk-based PRG       =       0.64
(mg/kg; TR = 10^{-6})        SF_o                                          (4')

where:

SF_o             =   oral slope factor in (mg/kg-day)^{-1}
```

Concentrations Based on Noncarcinogenic Effects. Total HI would be calculated by combining the appropriate oral RfD with the intake from soil:

$$HI = \frac{Intake\ from\ ingestion}{RfD_o}$$

Adding appropriate parameters, and then rearranging the equation to solve for concentration, results in Equation (5).

Equation (5') is the reduced version of Equation (5) using the standard default parameters, and is for calculating the risk-based PRG at a prespecified HI of 1. It combines the toxicity information of a chemical with standard exposure parameters for residential land use to generate the concentration of that chemical that corresponds to an HI of 1.

3.2   COMMERCIAL/INDUSTRIAL LAND USE

3.2.1   WATER

Once ground water is determined to be suitable for drinking, risk-based concentrations should be based on residential exposures. This is because the NCP seeks to require protection of ground water to allow for its maximum beneficial use (see Section 2.3). Thus, under the commercial/ industrial land-use scenario, risk-based PRGs for ground water are calculated according to procedures detailed in Section 3.1.1. Similarly, for surface water that is to be used for drinking, the risk-based PRGs should be calculated for residential populations, and not simply worker populations.

RESIDENTIAL SOIL — NONCARCINOGENIC EFFECTS

$$THI = \frac{C \times 10^{-6} \text{ kg/mg} \times EF \times IF_{soil/adj}}{RfD_o \times AT \times 365 \text{ days/yr}}$$

$$C \text{ (mg/kg; risk-based)} = \frac{THI \times AT \times 365 \text{ days/yr}}{1/RfD_o \times 10^{-6} \text{ kg/mg} \times EF \times IF_{soil/adj}}$$

(5)

where:

Parameters	Definition (units)	Default Value
C	chemical concentration in soil (mg/kg)	—
THI	target hazard index (unitless)	1
RfD_o	oral chronic reference dose (mg/kg-day)	chemical-specific
AT	averaging time (yr)	30 yr (for noncarcinogens, equal to ED [which is incorporated in $IF_{soil/adj}$])
EF	exposure frequency (days/yr)	350 days/yr
$IF_{soil/adj}$	age-adjusted ingestion factor (mg-yr/kg-day)	114 mg-yr/kg-day (see Equation (3))

REDUCED EQUATION: RESIDENTIAL SOIL — NONCARCINOGENIC EFFECTS

$$\text{Risk-based PRG (mg/kg; THI = 1)} = 2.7 \times 10^5 \, (RfD_o)$$

(5')

where:

RfD_o = oral chronic reference dose in mg/kg-day

3.2.2 SOIL

Under commercial/industrial land use, risk of the contaminant from soil is assumed to be due to direct ingestion, inhalation of volatiles from the soil, and inhalation of particulates from the soil, and is calculated for an adult worker only. For this type of land use, it is assumed for calculating default risk-based PRGs that there is greater potential for use of heavy equipment and related traffic in and around contaminated soils and thus greater potential for soils to be disturbed and produce particulate and volatile emissions than in most residential land-use areas. Additional exposure pathways (e.g., dermal exposure) are possible at some sites, while perhaps only one exposure pathway (e.g., direct ingestion of soil only) may be relevant at others; Appendix B may be used to identify relevant exposure pathways to be combined. In such cases, the risk is calculated by considering all the relevant exposure pathways identified in the RI.

In the default case illustrated below, intakes from the three exposure pathways are combined and the risk-based PRG is derived to be protective for exposures from all three pathways. In this case, the risk for a specific chemical from soil due to the three exposure pathways would be calculated as follows:

Total risk from soil = Risk from ingestion of soil (worker)

+ Risk from inhalation of volatiles from soil (worker)

+ Risk from inhalation of particulates from soil (worker)

It is possible to consider only exposure pathways of site-specific importance by deriving a site-specific risk-based PRG (e.g., using the equations in Appendix B).

Concentrations Based on Carcinogenic Effects.
Total risk for carcinogenic effects would be calculated by combining the appropriate inhalation and oral SFs with the three intakes from soil:

Total risk $=$ SF_c x Intake from ingestion of soil
(worker)

$+$ SF_i x Intake from inhalation of volatiles from soil (worker)

$+$ SF_i x Intake from inhalation of particulates (worker)

Adding appropriate parameters, and then rearranging the equation to solve for concentration, results in Equation (6). As discussed in more detail in Section 3.3.1, Equation (6a) is used to test the results of Equation (6).

Equation (6') is the reduced version of Equation (6) using the standard default parameters, and is used to calculate the risk-based PRG at a prespecified cancer risk level of 10^{-6}. It combines the toxicity information of a chemical with standard exposure parameters for commercial/industrial land use to generate the concentration of that chemical that corresponds to a 10^{-6} carcinogenic risk level due to that chemical.

Concentrations Based on Noncarcinogenic Effects. Total HI would be calculated by combining the appropriate oral and inhalation RfDs with the three intakes from soil:

HI $=$ $\dfrac{\text{Intake from ingestion}}{RfD_o}$

$+$ $\dfrac{(\text{Intake from inhalation of volatiles and particulates})}{RfD_i}$

Adding appropriate parameters, and then rearranging the equation to solve for concentration, results in Equation (7).

Equation (7') is the reduced version of Equation (7) using the standard default parameters, and is used to calculate the risk-based PRG at a prespecified HI of 1. It combines the toxicity information of a chemical with standard exposure parameters for commercial/industrial land use to generate the concentration of that chemical that corresponds to an HI of 1.

3.3 VOLATILIZATION AND PARTICULATE EMISSION FACTORS

3.3.1 SOIL-TO-AIR VOLATILIZATION FACTOR

The volatilization factor (VF) is used for defining the relationship between the concentration of contaminants in soil and the volatilized contaminants in air. This relationship was established as a part of the Hwang and Falco (1986) model developed by EPA's Exposure Assessment Group (EAG). Hwang and Falco present a method intended primarily to estimate the permissible residual levels associated with the cleanup of contaminated soils. This method has been used by EPA in estimating exposures to PCBs and 2,3,7,8-TCDD from contaminated soil (EPA 1986; EPA 1988a). One of the pathways considered in this method is the intake by inhalation of volatilized contaminants.

The basic principle of the Hwang and Falco model is applicable only if the soil contaminant concentration is at or below saturation. Saturation is the soil contaminant concentration at which the adsorptive limits of the soil particles and the solubility limits of the available soil moisture have been reached. Above saturation, pure liquid-phase contaminant is present in the soil. Under such conditions, the partial pressure of the pure contaminant and the partial pressure of air in the interstitial soil pore spaces cannot be calculated without first knowing the mole fraction of the contaminant in the soil. Therefore, above saturation, the PRG cannot be accurately calculated based on volatilization. Because of this limitation, the chemical concentration in soil (C) calculated using the VF must be compared with the soil saturation concentration (C_{sat}) calculated using Equation (6a) or (7a). If C is greater than C_{sat}, then the PRG is set equal to C_{sat}.

The VF presented in this section assumes that the contaminant concentration in the soil is homogeneous from the soil surface to the depth of concern and that the contaminated material is not covered by contaminant-free soil material. For the purpose of calculating VF, depth of concern is defined as the depth at which a near impenetrable layer or the permanent ground-water level is reached.

COMMERCIAL/INDUSTRIAL SOIL — CARCINOGENIC EFFECTS

$$TR = \frac{SF_o \times C \times 10^{-6}\ kg/mg \times EF \times ED \times IR_{soil}}{BW \times AT \times 365\ days/yr} + \frac{SF_i \times C \times EF \times ED \times IR_{air} \times (1/VF + 1/PEF)}{BW \times AT \times 365\ days/yr}$$

$$C\ (mg/kg;\ risk\text{-}based) = \frac{TR \times BW \times AT \times 365\ days/yr}{EF \times ED \times [(SF_o \times 10^{-6}\ kg/mg \times IR_{soil}) + (SF_i \times IR_{air} \times [1/VF + 1/PEF])]} \tag{6}$$

where:

Parameters	Definition (units)	Default Value
C	chemical concentration in soil (mg/kg)	—
TR	target excess individual lifetime cancer risk (unitless)	10^{-6}
SF_i	inhalation cancer slope factor $((mg/kg\text{-}day)^{-1})$	chemical-specific
SF_o	oral cancer slope factor $((mg/kg\text{-}day)^{-1})$	chemical-specific
BW	adult body weight (kg)	70 kg
AT	averaging time (yr)	70 yr
EF	exposure frequency (days/yr)	250 days/yr
ED	exposure duration (yr)	25 yr
IR_{soil}	soil ingestion rate (mg/day)	50 mg/day
IR_{air}	workday inhalation rate (m^3/day)	20 m^3/day
VF	soil-to-air volatilization factor (m^3/kg)	chemical-specific (see Section 3.3.1)
PEF	particulate emission factor (m^3/kg)	$4.63 \times 10^9\ m^3/kg$ (see Section 3.3.2)

$$C_{sat} = (K_d \times s \times n_m) + (s \times \Theta_m) \tag{6a}$$

where:

Parameters	Definition (units)	Default Value
C_{sat}	soil saturation concentration (mg/kg)	—
K_d	soil-water partition coefficient (L/kg)	chemical-specific, or $K_{oc} \times OC$
K_{oc}	organic carbon partition coefficient (L/kg)	chemical-specific
OC	organic carbon content of soil (fraction)	site-specific, or 0.02
s	solubility (mg/L-water)	chemical-specific
n_m	soil moisture content, expressed as a weight fraction	site-specific
Θ_m	soil moisture content, expressed as L-water/kg-soil	site-specific

---

REDUCED EQUATION: COMMERCIAL/INDUSTRIAL SOIL — CARCINOGENIC EFFECTS

$$Risk\text{-}based\ PRG\ (mg/kg;\ TR = 10^{-6}) = \frac{2.9 \times 10^{-4}}{[((5 \times 10^{-5}) \times SF_o) + (SF_i \times ((20/VF) + (4.3 \times 10^{-9})))]} \tag{6'}$$

where:

SF_o = oral slope factor in $(mg/kg\text{-}day)^{-1}$
SF_i = inhalation slope factor in $(mg/kg\text{-}day)^{-1}$
VF = chemical-specific soil-to-air volatilization factor in m^3/kg (see Section 3.3.1)

If PRG > C_{sat}, then set PRG = C_{sat} (where C_{sat} = soil saturation concentration (mg/kg); see Equation (6a) and Section 3.3.1).

COMMERCIAL/INDUSTRIAL SOIL — NONCARCINOGENIC EFFECTS

$$THI = \frac{C \times 10^{-6} \text{ kg/mg} \times EF \times ED \times IR_{soil}}{RfD_o \times BW \times AT \times 365 \text{ days/yr}} + \frac{C \times EF \times ED \times IR_{air} \times (1/VF + 1/PEF)}{RfD_i \times BW \times AT \times 365 \text{ days/yr}}$$

$$C \text{ (mg/kg; risk-based)} = \frac{THI \times BW \times AT \times 365 \text{ days/yr}}{ED \times EF \times [((1/RfD_o) \times 10^{-6} \text{ kg/mg} \times IR_{soil}) + ((1/RfD_i) \times IR_{air} \times (1/VF + 1/PEF))]} \qquad (7)$$

where:

Parameters	Definition (units)	Default Value
C	chemical concentration in soil (mg/kg)	—
THI	target hazard index (unitless)	1
RfD_o	oral chronic reference dose (mg/kg-day)	chemical-specific
RfD_i	inhalation chronic reference dose (mg/kg-day)	chemical-specific
BW	adult body weight (kg)	70 kg
AT	averaging time (yr)	25 yr (always equal to ED)
EF	exposure frequency (days/yr)	250 days/yr
ED	exposure duration (yr)	25 yr
IR_{soil}	soil ingestion rate (mg/day)	50 mg/day
IR_{air}	workday inhalation rate (m³/day)	20 m³/day
VF	soil-to-air volatilization factor (m³/kg)	chemical-specific (see Section 3.3.1)
PEF	particulate emission factor (m³/kg)	4.63×10^9 m³/kg (see Section 3.3.2)

$$C_{sat} = (K_d \times s \times n_m) + (s \times \Theta_m) \qquad (7a)$$

where:

Parameters	Definition (units)	Default Value
C_{sat}	soil saturation concentration (mg/kg)	—
K_d	soil-water partition coefficient (L/kg)	chemical-specific, or $K_{oc} \times OC$
K_{oc}	organic carbon partition coefficient (L/kg)	chemical-specific
OC	organic carbon content of soil (fraction)	site-specific, or 0.02
s	solubility (mg/L-water)	chemical-specific
n_m	soil moisture content, expressed as a weight fraction	site-specific
Θ_m	soil moisture content, expressed as L-water/kg-soil	site-specific

---

REDUCED EQUATION: COMMERCIAL/INDUSTRIAL SOIL — NONCARCINOGENIC EFFECTS

$$\text{Risk-based PRG (mg/kg; THI = 1)} = \frac{102}{[(5 \times 10^{-5}/RfD_o) + ((1/RfD_i) \times ((20/VF) + (4.3 \times 10^{-9})))]} \qquad (7')$$

where:

RfD_o = oral chronic reference dose in mg/kg-day

RfD_i = inhalation chronic reference dose in mg/kg-day

VF = chemical-specific soil-to-air volatilization factor in m³/kg (see Section 3.3.1)

If PRG > C_{sat}, then set PRG = C_{sat} (where C_{sat} = soil saturation concentration (mg/kg); see Equation (7a) and Section 3.3.1).

A chemical-specific value for VF is used in the standard default equations (Equations (6), (6'), (7), and (7') in Section 3.2.2) and is developed in Equation (8). The VF value calculated using Equation (8) has been developed for specific use in the other equations in this guidance; it may not be applicable in other technical contexts. Equation (8) lists the standard default parameters for calculating VF. If site-specific information is available, Equation (8) may be modified to calculate a VF that is more appropriate for the particular site. Supporting references should be consulted when substituting site-specific data to ensure that the model and specific parameters can be appropriately applied to the given site.

3.3.2 PARTICULATE EMISSION FACTOR

The particulate emission factor (PEF) relates the contaminant concentration in soil with the concentration of respirable particles (PM_{10}) in the air due to fugitive dust emissions from surface contamination sites. This relationship is derived by Cowherd (1985) for a rapid assessment procedure applicable to a typical hazardous waste site where the surface contamination provides a relatively continuous and constant potential for emission over an extended period of time (e.g., years). The particulate emissions from contaminated sites are due to wind erosion and, therefore, depend on the erodibility of the surface

---

SOIL-TO-AIR VOLATILIZATION FACTOR

$$VF \ (m^3/kg) \ = \ \frac{(LS \times V \times DH)}{A} \quad \times \quad \frac{(3.14 \times \alpha \times T)^{1/2}}{(2 \times D_e \times E \times K_{as} \times 10^{-3} \ kg/g)} \qquad (8)$$

where:

$$\alpha \ (cm^2/s) \ = \ \frac{(D_e \times E)}{E + (p_s)(1-E)/K_{as}}$$

Standard default parameter values that can be used to reduce Equation (8) are listed below. These represent "typical" values as identified in a number of sources. For example, when site-specific values are not available, the length of a side of the contaminated area (LS) is assumed to be 45 m; this is based on a contaminated area of 0.5 acre which approximates the size of an average residential lot. The "typical" values LS, DH, and V are from EPA 1986. "Typical" values for E, OC, and p_s are from EPA 1984, EPA 1988b, and EPA 1988f. Site-specific data should be substituted for the default values listed below wherever possible. Standard values for chemical-specific D_i, H, and K_{oc} can be obtained by calling the Superfund Health Risk Technical Support Center.

Parameter	Definition (units)	Default
VF	volatilization factor (m^3/kg)	—
LS	length of side of contaminated area (m)	45 m
V	wind speed in mixing zone (m/s)	2.25 m/s
DH	diffusion height (m)	2 m
A	area of contamination (cm^2)	20,250,000 cm^2
D_e	effective diffusivity (cm^2/s)	$D_i \times E^{0.33}$
E	true soil porosity (unitless)	0.35
K_{as}	soil/air partition coefficient (g soil/cm^3 air)	(H/K_d) × 41, where 41 is a units conversion factor
p_s	true soil density or particulate density (g/cm^3)	2.65 g/cm^3
T	exposure interval (s)	7.9 × 10^8 s
D_i	molecular diffusivity (cm^2/s)	chemical-specific
H	Henry's law constant (atm-m^3/mol)	chemical-specific
K_d	soil-water partition coefficient (cm^3/g)	chemical-specific, or K_{oc} × OC
K_{oc}	organic carbon partition coefficient (cm^3/g)	chemical-specific
OC	organic carbon content of soil (fraction)	site-specific, or 0.02

material. The equation presented below. Equation (9), is representative of a surface with "unlimited erosion potential." which is characterized by bare surfaces of finely divided material such as sandy agricultural soil with a large number ("unlimited reservoir") of erodible particles. Such surfaces erode at low wind speeds, and particulate emission rates are relatively time-independent at a given wind speed.

This model was selected for use in RAGS/HHEM Part B because it represents a conservative estimate for intake of particulates; it is used to derive Equations (6) and (7) in Section 3.2.2.

Using the default parameter values given in the box for Equation (9), the default PEF is equal to 4.63 x 10^9 m^3/kg. The default values necessary to calculate the flux rate for an "unlimited reservoir" surface (i.e., G, U$_m$, U$_t$, and F(x)) are provided by Cowherd (1985), and the remaining default values (i.e., for LS, V, and DH) are "typical" values (EPA 1986). If site-specific information is available. Equation (9) may be modified to calculate a PEF that is more appropriate for the particular site. Again, the original reference should be consulted when substituting site-specific data to ensure applicability of the model to specific site conditions.

PARTICULATE EMISSION FACTOR

$$PEF \ (m^3/kg) \ = \ \frac{LS \times V \times DH \times 3600 \ s/hr}{A} \quad \times \quad \frac{1000 \ g/kg}{0.036 \times (1-G) \times (U_m/U_t)^3 \times F(x)} \quad (9)$$

where:

Parameter	Definition (units)	Default
PEF	particulate emission factor (m^3/kg)	4.63 x 10^9 m^3/kg
LS	width of contaminated area (m)	45 m
V	wind speed in mixing zone (m/s)	2.25 m/s
DH	diffusion height (m)	2 m
A	area of contamination (m^2)	2025 m^2
0.036	respirable fraction (g/m^2-hr)	0.036 g/m^2-hr
G	fraction of vegetative cover (unitless)	0
U$_m$	mean annual wind speed (m/s)	4.5 m/s
U$_t$	equivalent threshold value of wind speed at 10 m (m/s)	12.8 m/s
F(x)	function dependent on U$_m$/U$_t$ (unitless)	0.0497 (determined using Cowherd 1985)

3.4 CALCULATION AND PRESENTATION OF RISK-BASED PRGs

The equations presented in this chapter can be used to calculate risk-based PRGs for both carcinogenic and noncarcinogenic effects. If both a carcinogenic and a noncarcinogenic risk-based PRG are calculated for a particular chemical, then the lower of the two values is considered the appropriate risk-based PRG for any given contaminant. The case-study box below illustrates a calculation of a risk-based PRG. A summary table — such as that in the final case-study box — should be developed to present both the risk-based PRGs and the ARAR-based PRGs. The table should be labeled as to whether it presents the concentrations that were developed during scoping or after the baseline risk assessment.

CASE STUDY: CALCULATE RISK-BASED PRGs[a]

Risk-based PRGs for ground water for isophorone, one of the chemicals detected in ground-water monitoring wells at the site, are calculated below. Initial risk-based PRGs for isophorone (carcinogenic and noncarcinogenic effects) are derived using Equations (1') and (2') in Section 3.1.1. Equations (1') and (2') combine the toxicity information of the chemical (oral RfD of 0.2 mg/kg-day and oral SF of 0.0039 (mg/kg-day)$^{-1}$; inhalation values are not available and, therefore, only the oral exposure route is considered) with standard exposure parameters. The calculated concentrations in mg/L correspond to a target risk of 10^{-6} and a target HQ of 1, as follows:

$$\text{Carcinogenic risk-based PRG} = \frac{1.7 \times 10^{-4}}{2(SF_o)}$$

$$= \frac{1.7 \times 10^{-4}}{2(0.0039)}$$

$$= 0.022 \text{ mg/L}$$

$$\text{Noncarcinogenic risk-based PRG} = \frac{73}{2 \, RfD_o}$$

$$= \frac{73}{2/0.2}$$

$$= 7.3 \text{ mg/L}$$

The lower of the two values (i.e., 0.022 mg/L) is selected as the appropriate risk-based PRG. Risk-based PRGs are calculated similarly for the other chemicals of concern.

---

[a] All information in this example is for illustration purposes only.

CASE STUDY: PRESENT PRGs DEVELOPED DURING SCOPING[*]

Site: XYZ Co.
Location: Anytown, Anystate
Medium: Ground Water

Land Use: Residential
Exposure Routes: Water Ingestion, Inhalation of Volatiles

Chemical	Risk-based PRGs (mg/L)[*]		ARAR-based PRG	
	10^{-6}	HQ = 1	Type	Concentration (mg/L)
Benzene	—	—	MCL	0.005
Carbon Tetrachloride	—	—	MCL	0.005
Ethylbenzene	—	—	MCLG	0.7[***]
			MCL	0.7
Hexane	—	0.33	—	—
Isophorone	0.022[**]	7.3	—	—
Triallate	—	0.47	—	—
1,1,2-Trichloroethane	—	—	MCLG	0.003[***]
			MCL	0.005
Vinyl chloride	—	—	MCL	0.002

[*] All information in this example is for illustration purposes only.

[*] These concentrations were calculated using the standard default equations in Chapter 3.

[**] Of the two potential risk-based PRGs for this chemical, this concentration is the selected risk-based PRG.

[***] Of the two potential ARAR-based PRGs for this chemical, this concentration is selected as the ARAR-based PRG.

CHAPTER 4

RISK-BASED PRGs FOR RADIOACTIVE CONTAMINANTS

This chapter presents standardized exposure parameters, derivations of risk equations, and "reduced" equations for calculating risk-based PRGs for radioactive contaminants for the pathways and land-use scenarios discussed in Chapter 2. In addition, a radiation site case study is provided at the end of the chapter to illustrate (1) how exposure pathways and radionuclides of potential concern (including radioactive decay products) are identified, (2) how initial risk-based PRGs for radionuclides are calculated using reduced equations based on information available at the scoping phase, and (3) how risk-based PRGs can be re-calculated using full risk equations and site-specific data obtained during the baseline risk assessment. Chapters 1 through 3 and Appendices A and B provide the basis for many of the assumptions, equations, and parameters used in this chapter, and therefore should be reviewed before proceeding further into Chapter 4. Also, Chapter 10 in RAGS/HHEM Part A should be consulted for additional guidance on conducting baseline risk assessments at sites contaminated with radioactive substances.

In general, standardized default exposure equations and parameters used to calculate risk-based PRGs for radionuclides are similar in structure and function to those equations and parameters developed in Chapter 3 for nonradioactive chemical carcinogens. Both types of risk equations:

- Calculate risk-based PRGs for each carcinogen corresponding to a pre-specified target cancer risk level of 10^{-6}. As mentioned in Section 2.8, target risk levels may be modified after the baseline risk assessment based on site-specific exposure conditions, technical limitations, or other uncertainties, as well as on the nine remedy selection criteria specified in the NCP.

- Use standardized default exposure parameters consistent with OSWER Directive 9285.6-03 (EPA 1991b). Where default parameters are

not available in that guidance document, other appropriate reference values are used and cited.

- Incorporate pathway-specific default exposure factors that generally reflect RME conditions.

There are, however, several important areas in which risk-based PRG equations and assumptions for radioactive contaminants differ substantially from those used for chemical contaminants. Specifically, unlike chemical equations, risk equations for radionuclides:

- Accept input quantities in units of activity (e.g., picocuries (pCi)) rather than in units of mass (e.g., milligrams (mg)). Activity units are more appropriate for radioactive substances because concentrations of radionuclides in sample media are determined by direct physical measurements of the activity of each nuclide present, and because adverse human health effects due to radionuclide intake or exposure are directly related to the amount, type, and energy of the radiation deposited in specific body tissues and organs.

- Consider the carcinogenic effects of radionuclides only. EPA designates all radionuclides as Class A carcinogens based on their property of emitting ionizing radiation and on the extensive weight of epidemiological evidence of radiation-induced cancer in humans. At most CERCLA radiation sites, potential health risks are usually based on the radiotoxicity, rather than the chemical toxicity, of each radionuclide present.

- Use cancer slope factors that are best estimates (i.e., median or 50th percentile values) of the age-averaged, lifetime excess total cancer risk per unit intake of a radionuclide (e.g., per pCi inhaled or ingested) or per unit external radiation exposure (e.g., per microRoentgen) to gamma-emitting

radionuclides. Slope factors given in IRIS and HEAST have been calculated for individual radionuclides based on their unique chemical, metabolic, and radiological properties and using a non-threshold, linear dose-response model. This model accounts for the amount of each radionuclide absorbed into the body from the gastrointestinal tract (by ingestion) or through the lungs (by inhalation), the distribution and retention of each radionuclide in body tissues and organs, as well as the age, sex, and weight of an individual at the time of exposure. The model then averages the risk over the lifetime of that exposed individual (i.e., 70 years). Consequently, radionuclide slope factors are not expressed as a function of body weight or time, and do not require corrections for gastrointestinal absorption or lung transfer efficiencies.

Risk-based PRG equations for radionuclides presented in the following sections of this chapter are derived initially by determining the total risk posed by each radioactive contaminant in a given pathway, and then by rearranging the pathway equation to solve for an activity concentration set equal to a target cancer risk level of 10^{-6}. At the scoping phase, these equations are "reduced" — and risk-based PRGs are calculated for each radionuclide of concern — using standardized exposure assumptions for each exposure route within each pathway and land-use combination. After the baseline risk assessment, PRGs can be recalculated using full risk equations and site-specific exposure information obtained during the RI.

4.1   RESIDENTIAL LAND USE

4.1.1   GROUND WATER OR SURFACE WATER

Under the residential land-use scenario, risk from ground-water or surface water radioactive contaminants is assumed to be due primarily to direct ingestion and inhalation of volatile radionuclides released from the water to indoor air. However, because additional exposure routes (e.g., external radiation exposure due to immersion) are possible at some sites for some radionuclides, while only one exposure route may be relevant at others, the risk assessor always should consider all relevant exposure routes and add or modify exposure routes as appropriate.

In the case illustrated below, risks from the two default exposure routes are combined, as follows:

Total risk from water	=	Risk from ingestion of radionuclides in water (adult)
	+	Risk from indoor inhalation of volatile radionuclides released from water (adult)

At the scoping phase, risk from indoor inhalation of volatile radionuclides is assumed to be relevant only for radionuclides with a Henry's Law constant of greater than 1×10^{-5} atm-m^3/mole and a molecular weight of less than 200 g/mole. However, radionuclides that do not meet these criteria also may, under certain site-specific water-use conditions, be volatilized into the air from water, and thus pose significant site risks (and require risk-based goals). Therefore, the ultimate decision regarding which contaminants should be considered must be made by the risk assessor on a site-specific basis following completion of the baseline risk assessment.

Total carcinogenic risk is calculated for each radionuclide separately by combining its appropriate oral and inhalation SFs with the two exposure pathways for water, as follows:

Total risk	=	SF_o x	Intake from ingestion of of radionuclides
	+	SF_i x	Intake from inhalation of volatile radionuclides

By including appropriate exposure parameters for each type of intake, rearranging and combining exposure terms in the total risk equation, and setting the target cancer risk level equal to 10^{-6}, the risk-based PRG equation is derived as shown in Equation (10).

Equation (10'), presented in the next box, is the reduced version of Equation (10) based on the standard default values listed below. It is used to calculate risk-based PRGs for radionuclides in water at a pre-specified cancer risk level of 10^{-6} by combining each radionuclide's toxicity data with the standard default values for residential land-use exposure parameters.

After the baseline risk assessment, the risk assessor may choose to modify one or more of the exposure parameter default values or assumptions

in the risk equations to reflect site-specific conditions. In this event, radionuclide PRGs should be calculated using Equation (10) instead of Equation (10').

4.1.2 SOIL

Under residential land-use conditions, risk from radionuclides in soil is assumed to be due to direct ingestion and external exposure to gamma radiation. Soil ingestion rates differ for children and adults, therefore age-adjusted ingestion rate factors are used in the soil pathway equation. Calculation of the risk from the external radiation exposure route assumes that any gamma-emitting radionuclide in soil is uniformly distributed in that soil within a finite soil depth and density, and dispersed in an infinite plane geometry.

The calculation of external radiation exposure risk also includes two additional factors, the gamma shielding factor (S_e) and the gamma exposure time factor (T_e), which can be adjusted to account for both attenuation of radiation fields due to shielding (e.g., by structures, terrain, or engineered barriers) and for exposure times of less than 24-hours per day, respectively. S_e is expressed as a fractional value between 0 and 1, delineating the possible risk reduction range from 0% to 100%, respectively, due to shielding. The default value of 0.2 for S_e for both residential and commercial/industrial land-use scenarios reflects the initial conservative assumption of a 20% reduction in external exposure due to shielding from structures (see EPA 1981). T_e is expressed as the quotient of the daily number of hours an individual is exposed directly to an external radiation field divided by the total number of exposure hours assumed each day for a given land-

use scenario (i.e., 24 hours for residential and 8 hours for commercial/industrial). The default value of 1 for T_e for both land-use scenarios reflects the conservative assumptions of a 24-hr exposure duration for residential populations (i.e., $24/24 = 1$) and an 8-hr exposure duration for workers (i.e., $8/8 = 1$). Values for both factors can (and, if appropriate, should) be modified by the risk assessor based on site-specific conditions.

In addition to direct ingestion of soil contaminated with radionuclides and exposure to external radiation from gamma-emitting radionuclides in soil, other soil exposure routes are possible, such as inhalation of resuspended radioactive particles, inhalation of volatile radionuclides, or ingestion of foodcrops contaminated by root or leaf uptake. The risk assessor should therefore identify all relevant exposure routes within the soil pathway and, if necessary, develop equations for risk-based PRGs that combine these exposure routes.

In the case illustrated below, the risk-based PRG is derived to be protective for exposure from the direct ingestion and external radiation routes. Total risk from soil due to ingestion and external radiation is calculated as follows:

Total risk from soil	=	Risk from direct ingestion of radionuclides in soil (child to adult)
	+	Risk from external radiation from gamma-emitting radionuclides in soil

Total risk for carcinogenic effects from each radionuclide of potential concern is calculated by combining the appropriate oral slope factor, SF_o, with the total radionuclide intake from soil, plus the appropriate external radiation slope factor, SF_e, with the radioactivity concentration in soil:

Total risk	=	SF_o x	Intake from direct ingestion of soil
	+	SF_e x	Concentration of gamma-emitting radionuclides in soil

Adding appropriate parameters, then combining and rearranging the equation to solve for concentration, results in Equation (11).

Equation (11') is the reduced version of Equation (11) based on the standard default values listed below. Risk-based PRGs for radionuclides

in soil are calculated for a pre-specified cancer risk level of 10^{-6}.

The age-adjusted soil ingestion factor ($IF_{soil/adj}$) used in Equation (11) takes into account the difference in soil ingestion for two exposure groups — children of one to six years and all other individuals from seven to 31 years. $IF_{soil/adj}$ is calculated for radioactive contaminants as shown in Equation (12). Section 3.1.2 provides additional discussion on the age-adjusted soil ingestion factor.

If any parameter values or exposure assumptions are adjusted after the baseline risk assessment to reflect site-specific conditions, soil PRGs should be calculated using Equation (11).

4.2 COMMERCIAL/INDUSTRIAL LAND USE

4.2.1 WATER

Under the commercial/industrial land use scenario, risk-based PRGs for radionuclides in ground water (and for radionuclides in surface water used for drinking water purposes) are based on residential exposures and calculated according to the procedures detailed in Section 4.1.1 (see Section 3.2.1 for the rationale for this approach). Risk-based PRGs should be calculated considering the possibility that both the worker and general population at large may be exposed to the same contaminated water supply.

4.2.2 SOIL

Under the commercial/industrial land use scenario, four soil exposure routes — direct ingestion, inhalation of volatile radionuclides, inhalation of resuspended radioactive particulates, and external exposure due to gamma-emitting radionuclides — are combined to calculate risk-based radionuclide PRGs in soil for adult worker exposures. Additional exposure routes (e.g., ingestion of foodcrops contaminated by radionuclide uptake) are possible at some sites, while only one exposure route (e.g., external radiation exposure only) may be relevant at others. The risk assessor should therefore consider and combine all relevant soil exposure routes, as necessary and appropriate, based on site-specific conditions.

RADIONUCLIDE PRGs: 'RESIDENTIAL SOIL — CARCINOGENIC EFFECTS

Total risk $=$ RS x $[(SF_e \times 10^{-3} g/mg \times EF \times IF_{soil\,adj}) + (SF_e \times 10^3 g/kg \times ED \times D \times SD \times (1-S_e) \times T_e)]$

$$RS\ (pCi/g;\ \text{risk-based}) = \frac{TR}{(SF_o \times 10^{-3} \times EF \times IF_{soil\,adj}) + (SF_e \times 10^3 \times ED \times D \times SD \times (1-S_e) \times T_e)} \quad (11)$$

where:

Parameters	Definition (units)	Default Value
RS	radionuclide PRG in soil (pCi/g)	—
TR	target excess individual lifetime cancer risk (unitless)	10^{-6}
SF_o	oral (ingestion) slope factor (risk/pCi)	radionuclide-specific
SF_e	external exposure slope factor (risk/yr per pCi/m²)	radionuclide-specific
EF	exposure frequency (days/yr)	350 days/yr
ED	exposure duration (yr)	30 yr
$IF_{soil\,adj}$	age-adjusted soil ingestion factor (mg-yr/day)	3600 mg-yr/day (see Equation (12))
D	depth of radionuclides in soil (m)	0.1 m
SD	soil density (kg/m²)	1.43×10^3 kg/m³
S_e	gamma shielding factor (unitless)	0.2 (see Section 4.1.2)
T_e	gamma exposure time factor (unitless)	1 (see Section 4.1.2)

REDUCED EQUATION FOR RADIONUCLIDE PRGs: RESIDENTIAL SOIL — CARCINOGENIC EFFECTS

$$\text{Risk-based PRG} \ (pCi/g;\ TR = 10^{-6}) = \frac{1 \times 10^{-6}}{1.3 \times 10^3 (SF_o) + 3.4 \times 10^6 (SF_e)} \quad (11')$$

where:

SF_o	=	oral (ingestion) slope factor (risk/pCi)
SF_e	=	external exposure slope factor (risk/yr per pCi/m²)

AGE-ADJUSTED SOIL INGESTION FACTOR

$$IF_{soil\,adj}\ (mg\text{-}yr/day) = (IR_{soil/age\,1-6} \times ED_{age\,1-6}) + (IR_{soil/age\,7-31} \times ED_{age\,7-31}) \quad (12)$$

where:

Parameters	Definition (units)	Default Value
$IF_{soil\,adj}$	age-adjusted soil ingestion factor (mg-yr/day)	3600 mg-yr/day
$IR_{soil/age\,1-6}$	ingestion rate of soil ages 1-6 (mg/day)	200 mg/day
$IR_{soil/age\,7-31}$	ingestion rate of soil ages 7-31 (mg/day)	100 mg/day
$ED_{age\,1-6}$	exposure duration during ages 1-6 (yr)	6 yr
$ED_{age\,7-31}$	exposure duration during ages 7-31 (yr)	24 yr

In the case illustrated below, total risk from radionuclides in soil is calculated as the summation of the individual risks from each of the four exposure routes listed above:

Total risk from soil = Risk from direct ingestion of radio-nuclides in soil (worker)

+ Risk from inhalation of volatile radionuclides (worker)

+ Risk from inhalation of resuspended radioactive particulates (worker)

+ Risk from external radiation from gamma-emitting radionuclides (worker)

Total risk for carcinogenic effects for each radionuclide is calculated by combining the appropriate ingestion, inhalation, and external exposure SF values with relevant exposure parameters for each of the four soil exposure routes as follows:

Total risk = SF_o x Intake from direct ingestion of radionuclides in soil (worker)

+ SF_i x Intake from inhalation of volatile radionuclides (worker)

+ SF_i x Intake from inhalation of resuspended radioactive particulates (worker)

+ SF_e x Concentration of gamma-emitting radionuclides in soil (worker)

Adding appropriate parameters, and then combining and rearranging the equation to solve for concentration, results in Equation (13).

Equation (13') below is the reduced version of Equation (13) based on the standard default values below and a pre-specified cancer risk level of 10^{-6}. It combines the toxicity information of a radionuclide with standard exposure parameters for commercial/industrial land use to generate the concentration of that radionuclide corresponding to a 10^{-6} carcinogenic risk level due to that radionuclide.

If any parameter default values or assumptions are changed after the baseline risk assessment to reflect site-specific conditions, radionuclide soil PRGs should be derived using Equation (13).

4.2.3 SOIL-TO-AIR VOLATILIZATION FACTOR

The VF, defined in Section 3.3.1 for chemicals, also applies for radioactive contaminants with the following exceptions.

- Most radionuclides are heavy metal elements and are non-volatile under normal, ambient conditions. For these radionuclides, VF values need not be calculated and the risk due to the inhalation of volatile forms of these nuclides can be ignored for the purposes of determining PRGs.

- A few radionuclides, such as carbon-14 (C-14), tritium (H-3), phosphorus-32 (P-32), sulfur-35 (S-35), and other isotopes, are volatile under certain chemical or environmental conditions, such as when they are combined chemically with volatile organic compounds (i.e., the so-called radioactively-labeled or "tagged" organic compounds), or when they can exist in the environment in a variety of physical forms, such as C-14 labeled carbon dioxide (CO_2) gas and tritiated water vapor. For these radionuclides, VF values should be calculated using the Hwang and Falco (1986) equation provided in Section 3.3.1 based on the chemical species of the compound with which they are associated.

- The naturally occurring, non-volatile radioisotopes of radium, namely Ra-226 and Ra-224, undergo radioactive decay and form inert, gaseous isotopes of radon, i.e., Rn-222 (radon) and Rn-220 (thoron), respectively. Radioactive radon and thoron gases emanate from their respective parent radium isotopes in soil, escape into the air, and can pose cancer risks if inhaled. For Ra-226 and Ra-224 in soil, use the default values shown in the box on page 40 for VF and for SF_i in Equation (12) and Equation (12').

4.3 RADIATION CASE STUDY

This section presents a case study of a hypothetical CERCLA radiation site, the ACME Radiation Co. site, to illustrate the process of calculating pathway-specific risk-based PRGs for radionuclides using the risk equations and assumptions presented in the preceding sections of this chapter. The radiation site case study is modeled after the XYZ Co. site study discussed in

---

RADIONUCLIDE PRGs: COMMERCIAL/INDUSTRIAL SOIL — CARCINOGENIC EFFECTS

Total risk $= \text{RS} \times \text{ED} \times [(\text{SF}_o \times 10^{-3}\text{g/mg} \times \text{EF} \times \text{IR}_{soil}) + (\text{SF}_i \times 10^{-3}\text{g/kg} \times \text{EF} \times \text{IR}_{air} \times 1/\text{VF})$

$+ (\text{SF}_i \times 10^{-3}\text{g/kg} \times \text{EF} \times \text{IR}_{air} \times 1/\text{PEF}) + (\text{SF}_e \times 10^{-3}\text{g/kg} \times \text{D} \times \text{SD} \times (1-\text{S}_e) \times \text{T}_e)]$

$$\text{RS} = \frac{\text{TR}}{\text{ED} \times [(\text{SF}_o \times 10^{-3} \times \text{EF} \times \text{IR}_{soil}) + (\text{SF}_i \times 10^{-3} \times \text{EF} \times \text{IR}_{air}) \times (1/\text{VF} + 1/\text{PEF}) + (\text{SF}_e \times 10^{-3} \times \text{D} \times \text{SD} \times (1-\text{S}_e) \times \text{T}_e)]} \tag{13}$$

(pCi/g; risk-based)

where:

Parameters	Definition (units)	Default Value
RS	radionuclide PRG in soil (pCi/g)	—
TR	target excess individual lifetime cancer risk (unitless)	10^{-6}
SF_i	inhalation slope factor (risk/pCi)	radionuclide-specific
SF_o	oral (ingestion) slope factor (risk/pCi)	radionuclide-specific
SF_e	external exposure slope factor (risk/yr per pCi/m²)	radionuclide-specific
EF	exposure frequency (days/yr)	250 days/yr
ED	exposure duration (yr)	25 yr
IR_{air}	workday inhalation rate of air (m³/day)	20 m³/day
IR_{soil}	daily soil ingestion rate (mg/day)	50 mg/day
VF	soil-to-air volatilization factor (m³/kg)	radionuclide-specific (see Section 4.2.3)
PEF	particulate emission factor (m³/kg)	4.63×10^9 m³/kg (see Section 3.3.2)
D	depth of radionuclides in soil (m)	0.1 m
SD	soil density (kg/m³)	1.43×10^3 kg/m³
S_e	gamma shielding factor (unitless)	0.2 (see Section 4.1.2)
T_e	gamma exposure factor (unitless)	1 (see Section 4.1.2)

REDUCED EQUATION FOR RADIONUCLIDE PRGs:
COMMERCIAL/INDUSTRIAL SOIL — CARCINOGENIC EFFECTS*

$$\text{Risk-based PRG} = \frac{1 \times 10^{-6}}{[(3.1 \times 10^{-2} (\text{SF}_o)) + ((1.3 \times 10^6/\text{VF} + 2.7 \times 10^{-2}) (\text{SF}_i)) + (2.9 \times 10^6 (\text{SF}_e))]} \tag{13'}$$

(pCi/g; TR = 10^{-6})

where:

SF_o = oral (ingestion) slope factor (risk/pCi)
SF_i = inhalation slope factor (risk/pCi)
SF_e = external exposure slope factor (risk/yr per pCi/m²)
VF = radionuclide-specific soil-to-air volatilization factor in m³/kg (see Section 3.3.1)

*NOTE: See Section 4.2.3 when calculating PRGs for Ra-226 and Ra-224.

Chapters 2 and 3. It generally follows a two-phase format which consists of a "at the scoping stage" phase wherein risk-based PRGs for radionuclides of potential concern are calculated initially using reduced equations based on PA/SI data, and then a second, "after the baseline risk assessment" phase wherein radionuclide PRGs are recalculated using full equations and modified site-specific parameter values based on RI/FS data.

Following an overview of the history and current status of the site presented in Section 4.3.1, Section 4.3.2 covers a number of important steps taken early in the scoping phase to calculate preliminary risk-based PRGs assuming a specific

SOIL DEFAULT VALUES FOR VF AND SF, FOR Ra-226 AND Ra-224		
Radium	Default VF Value $\left(\dfrac{pCi/t\ Ra}{pCi/m^3\ Rn}\,\right)^*$	Inhalation Slope Factor, SF, (risk/pCi)**
Ra-226	8	1.1E-11
Ra-224	200	4.7E-11

* Calculated using values taken from NCRP 1976 and UNSCEAR 1982: Assumptions: (1) an average Ra-226 soil concentration of 1 pCi/g associated with an average ambient Rn-222 air concentration of 120 pCi/m^3 and (2) an average Ra-224 soil concentration of 1 pCi/g associated with an average ambient Rn-220 air concentration of 5 pCi/m^3.

** Slope factor values are for Rn-222 (plus progeny) and for Rn-220 (plus progeny).

land-use scenario. Section 4.3.3 then discusses how initial assumptions and calculations can be modified when additional site-specific information becomes available.

4.3.1   SITE HISTORY

The ACME Radiation Co. site is an abandoned industrial facility consisting of a large factory building situated on ten acres of land surrounded by a high-density residential neighborhood. Established in 1925, the ACME Co. manufactured luminous watch dials and gauges using radium-based paint and employed approximately 100 workers, mostly women. With the declining radium market, ACME phased out dial production and expanded its operations in 1960 to include brokering (collection and disposal) of low-level radioactive waste (LLW). After the company was issued a state license in 1961, ACME began receiving LLW from various nearby hospitals and research laboratories. In 1975, acting on an anonymous complaint of suspected mishandling of radioactive waste, state officials visited the ACME Co. site and cited the company for numerous storage and disposal violations. After ACME failed to rectify plant conditions identified in initial and subsequent citations, the state first suspended, and then later revoked its operating license in 1978. Around the same time,

officials detected radium-226 (Ra-226) contamination at a few neighboring locations off site. However, no action was taken against the company at that time. When ACME filed for bankruptcy in 1985, it closed its facility before completing cleanup.

In 1987, the state and EPA conducted an aerial gamma survey over the ACME Radiation Co. site and surrounding properties to investigate the potential extent of radioactive contamination in these areas. The overflight survey revealed several areas of elevated exposure rate readings, although individual gamma-emitting radionuclides could not be identified. When follow-up ground level surveys were performed in 1988, numerous "hot spots" of Ra-226 were pinpointed at various locations within and around the factory building. Three large soil piles showing enhanced concentrations of Ra-226 were discovered along the southern border. Approximately 20 rusting drums labelled with LLW placards also were discovered outside under a covered storage area. Using ground-penetrating radar, EPA detected subsurface magnetic anomalies in a few locations within the property boundary which suggested the possibility of buried waste drums. Based on interviews with people living near the site and with former plant workers, the state believes that radium contaminated soil may have been removed from the ACME site in the past and used locally as fill material for the construction of new homes and roadbeds. Site access is currently limited (but not entirely restricted) by an existing security fence.

In 1988, EPA's regional field investigation team completed a PA/SI. Based on the PA/SI data, the ACME Radiation Co. site scored above 28.50 using the HRS and was listed on the National Priorities List in 1989. Early in 1990, an RI/FS was initiated and a baseline risk assessment is currently in progress.

4.3.2   AT THE SCOPING PHASE

In this subsection, several steps are outlined to show by example how initial site data are used at the scoping phase to calculate risk-based PRGs for radionuclides in specific media of concern. Appropriate sections of Chapters 2 and 3 should be consulted for more detailed explanations for each step considered below.

Identify Media of Concern. A large stream runs along the western border of the site and feeds into a river used by some of the local residents for fishing and boating. Supplemental water intake ducts for the municipal water treatment plant are located approximately 300 yards downriver, and the site is situated over an aquifer which serves as the primary drinking water supply for a community of approximately 33,000 people.

Analyses of ground water, soil, and stream sediment samples taken during the PA/SI revealed significant levels of radionuclide contamination. Potential sources of contamination include the soil piles, process residues in soil, and radionuclides leaking from buried drums. Air filter samples and surface water samples from the stream and river showed only background levels of activity. (Background concentrations were determined from analyses conducted on a limited number of air, ground water, surface water, and soil samples collected approximately one mile from the site.)

The data show that the media of potential concern at this site include ground water and soil. Although stream water and river water were not found to be contaminated, both surface water bodies may become contaminated in the future due to the migration of radionuclides from sediment, from the exposed soil piles, or from leaking drums. Thus, surface water is another medium of potential concern.

For simplicity, only soil will be discussed as the medium of concern during the remainder of this case study. Procedures discussed for this medium can nevertheless be applied in a similar manner to all other media of concern.

Identify Initial List of Radionuclides of Concern. The PA/SI for the ACME Radiation Co. site identified elevated concentrations of five radionuclides in soil (Ra-226, tritium (H-3), carbon-14 (C-14), cesium (Cs-137), and strontium (Sr-90)). These comprise the initial list of radionuclides of potential concern.

Site records indicate that radioisotopes of cobalt (Co-60), phosphorus (P-32), sulfur (S-35), and americium (Am-241 and Am-243) were included on the manifests of several LLW drums in the storage area and on the manifests of other drums suspected to be buried onsite. Therefore, although not detected in any of the initial soil samples analyzed, Co-60, P-32, S-35, Am-241, and

Am-243 are added to the list for this medium because of their potential to migrate from leaking buried drums into the surrounding soil.

Identify Probable Land Uses. The ACME Radiation Co. site is located in the center of a rapidly developing suburban community comprised of single and multiple family dwellings. The area immediately encircling the site was recently re-zoned for residential use only; existing commercial and light industrial facilities are currently being relocated. Therefore, residential use is determined to be the most reasonable future land use for this site.

Identify Exposure Pathways, Parameters, and Equations. During the scoping phase, available site data were neither sufficient to identify all possible exposure pathways nor adequate enough to develop site-specific fate and transport equations and parameters. Therefore, in order to calculate initial risk-based PRGs for radionuclides of potential concern in soil, the standardized default soil exposure equation and assumptions provided in this chapter for residential land use in Section 4.1.2 are selected. (Later in this case study, examples are provided to illustrate how the full risk equation (Equation (11)) and assumptions are modified when baseline risk assessment data become available.)

For the soil pathway, the exposure routes of concern are assumed to be direct ingestion of soil contaminated with radionuclides and exposure to external radiation from gamma-emitting radionuclides. Again, although soil is the only medium discussed throughout this case study, exposure pathways, parameters, equations, and eventually risk-based concentrations would need to be identified and developed for all other media and exposure pathways of potential concern at an actual site.

Identify Toxicity Information. To calculate media-specific risk-based PRGs, reference toxicity values for radiation-induced cancer effects are required (i.e., SFs). As stated previously, soil ingestion and external radiation are the exposure routes of concern for the soil pathway. Toxicity information (i.e., oral, inhalation, and external exposure SFs) for all radionuclides of potential concern at the ACME Radiation Co. site are obtained from IRIS or HEAST, and are shown in the box on the following page.

RADIATION CASE STUDY:
TOXICITY INFORMATION FOR RADIONUCLIDES OF POTENTIAL CONCERN*

Radionuclides	Radioactive Half-life (yr)	Decay Mode	ICRP Lung Classification	Inhalation Slope Factor (risk/pCi)	Ingestion Slope Factor (risk/pCi)	External Exposure Slope Factor (risk/yr per pCi/m³)
H-3	12	beta	g	7.8E-14	5.5E-14	NA
C-14	5730	beta	g	6.4E-15	9.1E-13	NA
P-32	0.04	beta	D	3.0E-12	3.5E-12	NA
S-35	0.24	beta	D	1.9E-13	2.2E-13	NA
Co-60	5	beta/gamma	Y	1.6E-10	1.5E-11	1.3E-10
Sr-90	29	beta	D	5.6E-11	3.3E-11	NA
Cs-137	30	beta	D	1.9E-11	2.8E-11	NA
Ra-226	1600	alpha/gamma	W	3.0E-09	1.2E-10	4.2E-13
Am-241	432	alpha/gamma	W	4.0E-08	3.1E-10	1.6E-12
Am-243	7380	alpha/gamma	W	4.0E-08	3.1E-10	3.6E-12

* Sources: HEAST and Federal Guidance Report No. 11. All information in this example is for illustration only.

NA = Not applicable (i.e., these radionuclides are not gamma-emitters and the direct radiation exposure pathway can be ignored).

Calculate Risk-based PRGs. At this step, risk-based PRGs are calculated for each radionuclide of potential concern using the reduced risk Equation (11') in Section 4.1.2. SF values obtained from IRIS and HEAST, and standardized default values for parameters for the residential land-use scenario. To calculate the risk-based PRG for Co-60 at a pre-specified target risk level of 10^{-6}, for example, its ingestion SF of 1.5×10^{-11} and its external exposure SF of 1.3×10^{-10} are substituted into Equation (11'), along with the standardized default values, as follows:

$$\text{Risk-based PRG for Co-60 (pCi/g; TR } = 10^{-6}) = \frac{1 \times 10^{-6}}{1.3 \times 10^{3}(SF_o) + 3.4 \times 10^{6} (SF_e)}$$

where:

SF_o = oral (ingestion) slope factor for Co-60 = 1.5×10^{-11} (risk/pCi)

SF_e = external exposure slope factor for Co-60 = 1.3×10^{-10} (risk/yr per pCi/m^2)

Substituting the values for SF_o and SF_e for Co-60 into Equation (11') results in:

Risk-based PRG for Co-60 (pCi/g; TR = 10^{-6}) =

$$\frac{1 \times 10^{-6}}{[(1.3 \times 10^{3})(1.5 \times 10^{-11}) + (3.4 \times 10^{6})(1.3 \times 10^{-10})]}$$

= 0.002 pCi of Co-60/g of soil

In a similar manner, risk-based PRGs can be calculated for all other radionuclides of concern in soil at the ACME Radiation Co. site. These PRGs are presented in the next box.

4.3.3 AFTER THE BASELINE RISK ASSESSMENT

In this subsection, several steps are outlined which demonstrate how site-specific data obtained during the baseline risk assessment can be used to recalculate risk-based PRGs for radionuclides in soil. Appropriate sections of Chapters 2 and 3 should be consulted for more detailed explanations for each step considered below.

Review Media of Concern. During the RI/FS, gamma radiation surveys were conducted in the yards of several homes located within a two-block radius of the ACME Radiation Co. site. Elevated exposure rates, ranging from approximately two to four times the natural background rate, were

RADIATION CASE STUDY:
INITIAL RISK-BASED PRGs FOR
RADIONUCLIDES IN SOIL.*

Radionuclides	Risk-based Soil PRG (pCi/g)
H-3	14,000 *
Sr-90 (only)	23
P-32	220
S-35	3,500
C-14	850
Co-60	0.002
Cs-137 (only)	27
Ra-226 (only)	0.6
Am-241	0.2
Am-243 (only)	7.9×10^{-2}

* Calculated for illustration only using Equation (11') in Section 4.1.2. Values have been rounded off.

measured on properties immediately bordering the site. Measurements onsite ranged from 10 to 50 times background. In both cases, enhanced soil concentrations of Ra-226 (and decay products) and several other gamma-emitting radionuclides were discovered to be the sources of these elevated exposure rates. Therefore, soil continues as a medium of potential concern.

Modify List of Radionuclides of Concern. During scoping, five radionuclides (Ra-226, H-3, C-14, Cs-137, and Sr-90) were detected in elevated concentrations in soil samples collected at the ACME Radiation Co. site. These made up the initial list of radionuclides of potential concern. Although not detected during the first round of sampling, five additional radionuclides (P-32, S-35, Co-60, Am-241, and Am-243) were added to this list because of their potential to migrate from buried leaking drums into the surrounding soil.

With additional RI/FS data, some radionuclides are now added to the list, while others are dropped. For example, soil analyses failed to detect P-32 (14-day half-life) or S-35 (87-day half-life) contamination. Decay correction calculations strongly suggest that these radionuclides should not be present onsite in detectable quantities after an estimated burial time of 30 years. Therefore, based on these data, P-32 and S-35 are dropped from the list. Soil data also confirm that decay products of Ra-226, Sr-90, Cs-137, and Am-243 (identified in the first box below)

are present in secular equilibrium (i.e., equal activity concentrations) with their respective parent isotopes.

Assuming secular equilibrium, slope factors for the parent isotope and each of its decay series members are summed. Parent isotopes are designated with a "+D" to indicate the composite slope factors of its decay chain (shown in bold face in the second box below). Thus, Ra-226+D, Sr-90+D, Cs-137+D, and Am-243+D replace their respective single-isotope values in the list of radionuclides of potential concern, and their composite SFs are used in the full soil pathway equation to recalculate risk-based concentrations.

RADIATION CASE STUDY: DECAY PRODUCTS

Parent Radionuclide	Decay Product(s) (Half-life)
Ra-226	Rn-222 (4 days), Po-218 (3 min), Pb-214 (27 min), Bi-214 (20 min), Po-214 (<1 s), Pb-210 (22 yr), Bi-210 (5 days), Po-210 (138 days)
Sr-90	Y-90 (14 hr)
Cs-137	Ba-137m (2 min)
Am-243	Np-239 (2 days)

RADIATION CASE STUDY: SLOPE FACTORS FOR DECAY SERIES[a]

Slope Factors

Decay Series	Inhalation	Ingestion	External
Ra-226	3.0E-09	1.2E-10	4.2E-13
Rn-222	7.2E-13	—	2.2E-14
Po-218	5.8E-13	2.8E-14	0.0E+00
Pb-214	2.9E-12	1.8E-13	1.5E-11
Bi-214	2.2E-12	1.4E-13	8.0E-11
Po-214	2.8E-19	1.0E-20	4.7E-15
Pb-210	1.7E-09	6.5E-10	1.8E-13
Bi-210	8.1E-11	1.9E-12	0.0E+00
Po-210	2.7E-09	2.6E-10	4.8E-16
Ra-226+D	**7.5E-09**	**1.0E-09**	**9.6E-11**
Sr-90	5.6E-11	3.3E-11	0.0E+00
Y-90	5.5E-12	3.2E-12	0.0E+00
Sr-90+D	**6.2E-11**	**3.6E-11**	**0.0E+00**
Cs-137	1.9E-11	2.8E-11	0.0E+00
Ba-137m	6.0E-16	2.4E-15	3.4E-11
Cs-137+D	**1.9E-11**	**2.8E-11**	**3.4E-11**
Am-243	4.0E-08	3.1E-10	3.6E-12
Np-239	1.5E-12	9.3E-13	1.1E-11
Am-243+D	**4.0E-08**	**3.1E-10**	**1.5E-11**

[a] All information in this example is for illustration purposes only.

Review Land-use Assumptions. At this step, the future land-use assumption chosen during scoping is reviewed. Since the original assumption of future residential land use is supported by RI/FS data, it is not modified.

Modify Exposure Pathways, Parameters, and Equations. Based on site-specific information, the upper-bound residence time for many of the individuals living near the ACME Radiation Co. site is determined to be 45 years rather than the default value of 30 years. Therefore, the exposure duration parameter used in Equation (11) in Section 4.1.2 is substituted accordingly. It is also determined that individuals living near the site are only exposed to the external gamma radiation field approximately 18 hours each day, and that their homes provide a shielding factor of about 0.5 (i.e., 50%). Therefore, values for T_e and S_e are changed to 0.75 (i.e., 18 hr/24 hr) and 0.5, respectively.

Modify Toxicity Information. As discussed above in the section on modifying the list of radionuclides of concern, oral, inhalation, and external exposure slope factors for Ra-226, Sr-90, Cs-137, and Am-243 were adjusted to account for the added risks (per unit intake and/or exposure) contributed by their respective decay series members that are in secular equilibrium.

Recalculate Risk-based PRGs. At this step, risk-based PRGs are recalculated for all remaining radionuclides of potential concern using the full risk equation for the soil pathway (i.e., Equation (11)) modified by revised site-specific assumptions regarding exposures, as discussed above.

To recalculate the risk-based PRG for Co-60 at a pre-specified target risk level of 10^{-6}, for example, its ingestion SF of 1.5×10^{-11}, and its external exposure SF of 1.3×10^{-10} are substituted into Equation (11), along with other site-specific parameters, as shown in the next box.

In a similar manner, risk-based PRGs can be recalculated for all remaining radionuclides of potential concern in soil at the ACME Radiation Co. site. These revised PRGs are presented in the box on the next page. In those cases where calculated risk-based PRGs for radionuclides are below current detection limits, risk assessors should contact the Superfund Health Risk Technical Support Center for additional guidance.

RADIATION CASE STUDY: REVISED RISK EQUATION FOR RESIDENTIAL SOIL

$$\text{RS for Co-60 (pCi/g; risk-based)} = \frac{TR}{(SF_o \times 10^{-3} \times EF \times IF_{soil/adj}) + (SF_e \times 10^{5} \times ED \times D \times SD \times (1-S_e) \times T_e)}$$

$$= 0.003 \text{ pCi/g}$$

where:

Parameters	Definition (units)	Revised Value
RS	radionuclide PRG in soil (pCi/g)	—
TR	target excess individual lifetime cancer risk (unitless)	10^{-6}
SF_o	oral (ingestion) slope factor (risk/pCi)	1.5×10^{-11} (risk/pCi)
SF_e	external exposure slope factor (risk/yr per pCi/m^2)	1.3×10^{-10} (risk/yr per pCi/m^2)
EF	exposure frequency (days/yr)	350 days/yr
ED	exposure duration (yr)	45 yr
$IF_{soil/adj}$	age-adjusted soil ingestion factor (mg-yr/day)	5100 mg-yr/day
D	depth of radionuclides in soil (m)	0.1 m
SD	soil density (kg/m^3)	1.43×10^{3} kg/m^3
S_e	gamma shielding factor (unitless)	0.5
T_e	gamma exposure time factor (unitless)	0.75

(Note: To account for the revised upper-bound residential residency time of 45 years, the age-adjusted soil ingestion factor was recalculated using the equation in Section 4.1.2 and an adult exposure duration of 39 years for individuals 7 to 46 years of age.)

RADIATION CASE STUDY:
REVISED RISK-BASED PRGs FOR RADIONUCLIDES IN SOIL*

Radionuclides	Risk-based Soil PRG (pCi/g)
H-3	10,200
Sr-90+D	20
C-14	620
Co-60	0.003
Cs-137+D	0.01
Ra-226+D	0.004
Am-241	0.2
Am-243+D	0.03

* Calculated for illustration only. Values have been rounded off.

REFERENCES

Andelman, J.B. 1990. *Total Exposure to Volatile Organic Chemicals in Potable Water.* N.M. Ram, R.F. Christman, K.P. Cantor (eds.). Lewis Publishers.

Cowherd, C., Muleski, G., Engelhart, P., and Gillete, D. 1985. *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination.* Prepared for EPA Office of Health and Environmental Assessment. EPA/600/8-85/002.

Environmental Protection Agency (EPA). 1981. *Population Exposures to External Natural Radiation Background in the U.S.* Office of Radiation Programs. ORP/SEPD-80-12.

EPA. 1984. *Evaluation and Selection of Models for Estimating Air Emissions from Hazardous Waste Treatment, Storage, and Disposal Facilities.* Office of Air Quality Planning and Standards. EPA/450/3-84/020.

EPA. 1986. *Development of Advisory Levels for PCBs Cleanup.* Office of Health and Environmental Assessment. EPA/600/21.

EPA. 1988a. *CERCLA Compliance With Other Laws Manual, Part I (Interim Final).* Office of Emergency and Remedial Response. EPA/540/G-89/006 (OSWER Directive #9234.1-01).

EPA. 1988b. *Estimating Exposures to 2,3,7,8-TCDD (External Review Draft).* Office of Health and Environmental Assessment. EPA/600/6-88/005A.

EPA. 1988c. *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA.* Interim Final. Office of Emergency and Remedial Response. EPA/540/G-89/004 (OSWER Directive #9355.3-01).

EPA. 1988d. *Guidance on Remedial Actions for Contaminated Ground Water at Superfund Sites.* Interim Final. Office of Emergency and Remedial Response. EPA/540/G-88/003 (OSWER Directive #9283.1-2).

EPA. 1988f. *Superfund Exposure Assessment Manual.* Office of Emergency and Remedial Response. EPA/540/1-88/001 (OSWER Directive 9285.5-1).

EPA. 1988. Availability of the Integrated Risk Information System (IRIS). 53 *Federal Register* 20162.

EPA. 1989a. *CERCLA Compliance With Other Laws Manual, Part II: Clean Air Act and Other Environmental Statutes and State Requirements.* Office of Emergency and Remedial Response. EPA/540/G-89/009 (OSWER Directive #9234.1-01).

EPA. 1989b. *Interim Final Guidance on Preparing Superfund Decision Documents.* Office of Emergency and Remedial Response. OSWER Directive 9355.3-02.

EPA. 1989c. *Methods for Evaluating the Attainment of Cleanup Standards* (Volume 1: Soils and Solid Waste). Statistical Policy Branch. NTIS #PB89-234-959/AS.

EPA. 1989d. *Risk Assessment Guidance for Superfund: Volume I — Human Health Evaluation Manual (Part A, Baseline Risk Assessment).* Interim Final. Office of Emergency and Remedial Response. EPA/540/1-89/002.

EPA. 1990a. *Catalog of Superfund Program Publications.* Office of Emergency and Remedial Response. OSWER Directive 9200.7-02A.

EPA. 1990b. *Guidance for Data Usability in Risk Assessment.* Office of Solid Waste and Emergency Response. EPA/540/G-90/008 (OSWER Directive #9285.7-05).

EPA. 1990c. *Guidance on Remedial Actions for Superfund Sites with PCB Contamination.* Office of Emergency and Remedial Response. EPA/540/G-90/007 (OSWER Directive #9355.4-01).

EPA. 1990d. "National Oil and Hazardous Substances Pollution Contingency Plan (Final Rule)." 40 CFR Part 300; 55 *Federal Register* 8666.

EPA. 1991a. *Conducting Remedial Investigations/Feasibility Studies for CERCLA Municipal Landfill Sites.* Office of Emergency and Remedial Response. EPA/540/P-91/001 (OSWER Directive #9355.3-11).

EPA. 1991b. *Risk Assessment Guidance for Superfund. Vol. 1. Human Health Evaluation Manual. Supplemental Guidance: "Standard Default Exposure Factors."* (Interim Final). Office of Emergency and Remedial Response. OSWER Directive 9285.6-03.

EPA. 1991c. *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions.* Office of Solid Waste and Emergency Response. OSWER Directive 9355.0-30.

EPA. 1991d. *Risk Assessment Guidance for Superfund: Volume 1 — Human Health Evaluation Manual (Part C. Risk Evaluation of Remedial Alternatives).* Interim. Office of Emergency and Remedial Response. OSWER Directive 9285.7-01C.

EPA. *Health Effects Assessment Summary Tables (HEAST).* Published quarterly by the Office of Research and Development and Office of Solid Waste and Emergency Response. NTIS #PB 91-921100.

Hwang. S.T., and Falco. J.W. 1986. *Estimation of Multimedia Exposures Related to Hazardous Waste Facilities.* Cohen, Y. (ed). Plenum Publishing Corp.

APPENDIX A

ILLUSTRATIONS OF CHEMICALS THAT "LIMIT" REMEDIATION

In many cases, one or two chemicals will drive the cleanup at a site, and the resulting cumulative medium or site risk will be approximately equal to the potential risk associated with the individual remediation goals for these chemicals. These "limiting chemicals" are generally either chemicals that are responsible for much of the baseline risk (because of either high toxicity or presence in high concentrations), or chemicals that are least amenable to the selected treatment method. By cleaning up these chemicals to their goals, the other chemicals typically will be cleaned up to levels much lower than their corresponding goals. The example given in the box below provides a simple illustration of this principle.

The actual circumstances for most remediations will be much more complex than those described in the example (e.g., chemicals will be present at different baseline concentrations and will be treated/removed at differing rates); however, the same principle of one or perhaps two chemicals limiting the site cleanup usually applies, even in more complex cases.

Unless much is known about the performance of a remedy with respect to all the chemicals present at the site, it may not be possible to determine which of the site contaminants will drive the final risk until well into remedy implementation. Therefore, it generally is not possible to predict the cumulative risk that will be present at the site during or after remediation. In some situations, enough will be known about the site conditions and the performance of the remedy to estimate post-remedy concentrations of chemicals or to identify the chemical(s) that will dominate the residual risk. If this type of information is available, it may be necessary to modify the risk-based remediation goals for individual chemicals.

SIMPLE ILLUSTRATION OF A CHEMICAL THAT LIMITS REMEDIATION

Two chemicals (A and B) are present in ground water at a site at the same baseline concentrations. Remediation goals were identified for both A and B. Chemical A's goal is 0.5 ug/L, which is associated with a potential risk of 10^{-6}. Chemical B's goal is 10 ug/L, which is also associated with a potential risk of 10^{-6}. The calculated cumulative risk at remediation goals is therefore 2×10^{-6}. Assuming for the purposes of this illustration that A and B are treated or removed at the same rate, then the first chemical to meet its goal will be B. Remediation must continue at this site, however, until the goal for chemical A has been met. When the concentration of A reaches 0.5 ug/L, then remediation is complete. A is at its goal and has a risk of 10^{-6}. B is at 1/20 of its goal with a risk of 5×10^{-8}. The total risk ($1 \times 10^{-6} + 5 \times 10^{-8}$) is approximately 10^{-6} and is due to the presence of A.

This example illustrates that the final risk for a chemical may not be equal to the potential risk associated with its remediation goal, and, in fact, can be much less than this risk. Although the potential risk associated with Chemical B's goal is 10^{-6}, the final residual risk associated with B is 5×10^{-8}. Thus, if one were to calculate the cumulative risk at PRGs prior to remedy implementation, one would estimate total medium risk of 2×10^{-6}, however, the residual cumulative risk after remediation is 1×10^{-6}.

APPENDIX B

RISK EQUATIONS FOR INDIVIDUAL EXPOSURE PATHWAYS

This appendix presents individual risk equations for each exposure pathway presented in Chapter 3. These individual risk equations can be used and rearranged to derive full risk equations required for calculating risk-based PRGs. Depending on the exposure pathways that are of concern for a land-use and medium combination, different individual risk equations can be combined to derive the full equation reflecting the cumulative risk for each chemical within the medium. See Chapter 3 for examples of how equations are combined and how they need to be rearranged to solve for risk-based PRGs. Note that in this appendix, the term HQ is used to refer to the risk level associated with noncarcinogenic effects since the equations are for a single contaminant in an individual exposure pathway.

The following sections list individual risk equations for the ground water, surface water, and soil pathways. Risk equations for exposure pathways not listed below can be developed and combined with those listed. In particular, dermal exposure and ingestion of ground water contaminated by soil leachate, for which guidance is currently being developed by EPA, could be included in the overall exposure pathway evaluation.

B.1 GROUND WATER OR SURFACE WATER — RESIDENTIAL LAND USE

Both the ingestion of water and the inhalation of volatiles are included in the standard default equations in Section 3.1.1. If only one of these exposure pathways is of concern at a particular site, or if one or both of these pathways needs to be combined with additional pathways, a site-specific equation can be derived.

The parameters used in the equations presented in the remainder of this section are explained in the following text box.

B.1.1 INGESTION

The cancer risk due to ingestion of a contaminant in water is calculated as follows:

PARAMETERS FOR SURFACE WATER/GROUND WATER — RESIDENTIAL LAND USE		
Parameter	Definition	Default Value
C	chemical concentration in water (mg/L)	—
SF_i	inhalation cancer slope factor $((mg/kg\text{-}day)^{-1})$	chemical-specific
SF_o	oral cancer slope factor $((mg/kg\text{-}day)^{-1})$	chemical-specific
RfD_o	oral chronic reference dose (mg/kg-day)	chemical-specific
RfD_i	inhalation chronic reference dose (mg/kg-day)	chemical-specific
BW	adult body weight (kg)	70 kg
AT	averaging time (yr)	70 yr for cancer risk
		30 yr for noncancer HI (equal to ED)
EF	exposure frequency (days/yr)	350 days/yr
ED	exposure duration (yr)	30 yr
K	volatilization factor (L/m^3)	0.0005 x 1000 L/m^3 (Andelman 1990)
IR_a	daily indoor inhalation rate (m^3/day)	15 m^3/day
IR_w	daily water ingestion rate (L/day)	2 L/day

Risk from ingestion $=$ $\dfrac{SF_o \times C \times IR_w \times EF \times ED}{BW \times AT \times 365\ days/yr}$
of water (adult)

The noncancer HQ due to ingestion of a contaminant in water is calculated as follows:

HQ due to ingestion $=$ $\dfrac{C \times IR_w \times EF \times ED}{RfD_o \times BW \times AT \times 365\ days/yr}$
of water (adult)

B.1.2   INHALATION OF VOLATILES

The cancer risk due to inhalation of a volatile contaminant in water is calculated as follows:

Risk from inhalation of volatiles in water (adult) $=$ $\dfrac{SF_i \times C \times K \times IR_a \times EF \times ED}{BW \times AT \times 365\ days/yr}$

The noncancer HQ due to inhalation of a volatile contaminant in water is calculated as follows:

HQ due to inhalation of volatiles in water (adult) $=$ $\dfrac{C \times K \times IR_a \times EF \times ED}{RfD_i \times BW \times AT \times 365\ days/yr}$

B.2   SOIL — RESIDENTIAL LAND USE

Only the first exposure pathway below — ingestion of soil — is included in the standard default equations in Section 3.1.2. If additional exposure pathways, including inhalation of volatiles

and/or inhalation of particulates, are of concern at a particular site, then a site-specific equation can be derived.

The parameters used in the equations presented in the remainder of this section are explained in the text box below.

B.2.1   INGESTION OF SOIL

The cancer risk from ingestion of contaminated soil is calculated as follows:

Risk from ingestion of soil $=$ $\dfrac{SF_o \times C \times 10^{-6}\ kg/mg \times EF \times IF_{soil/adj}}{AT \times 365\ days/yr}$

The noncancer HQ from ingestion of contaminated soil is calculated as follows:

HQ from ingestion of soil $=$ $\dfrac{C \times 10^{-6}\ kg/mg \times EF \times IF_{soil/adj}}{RfD_o \times AT \times 365\ days/yr}$

B.2.2   INHALATION OF VOLATILES

The cancer risk caused by inhalation of volatiles released from contaminated soil is:

Risk from inhalation of volatiles $=$ $\dfrac{SF_i \times C \times ED \times EF \times IR_{air} \times (1/VF)}{AT \times BW \times 365\ days/yr}$

The equation for calculating the noncancer HQ from inhalation of volatiles released from soil is:

PARAMETERS FOR SOIL — RESIDENTIAL LAND USE

Parameter	Definition	Default Value
C	chemical concentration in soil (mg/kg)	—
SF_i	inhalation cancer slope factor ((mg/kg-day)$^{-1}$)	chemical-specific
SF_o	oral cancer slope factor ((mg/kg-day)$^{-1}$)	chemical-specific
RfD_o	oral chronic reference dose (mg/kg-day)	chemical-specific
RfD_i	inhalation chronic reference dose (mg/kg-day)	chemical-specific
BW	adult body weight (kg)	70 kg
AT	averaging time (yr)	70 yr for cancer risk
		30 yr for noncancer HI (equal to ED)
EF	exposure frequency (days/yr)	350 days/yr
ED	exposure duration (yr)	30 yr
IR_a	daily indoor inhalation rate (m^3/day)	15 m^3/day
$IF_{soil/adj}$	age-adjusted soil ingestion factor (mg-yr/kg-day)	114 mg-yr/kg-day
VF	soil-to-air volatilization factor (m^3/kg)	chemical specific (see Section 3.3.1)
PEF	particulate emission factor (m^3/kg)	4.63 x 10^9 m^3/kg (see Section 3.3.2)

HQ from $=$ $\dfrac{C \times ED \times EF \times IR_{air} \times (1/VF)}{RfD_i \times BW \times AT \times 365\ days/yr}$
inhalation
of volatiles

B.2.3   INHALATION OF PARTICULATES

Cancer risk due to inhalation of contaminated soil particulates is calculated as:

Risk from $=$ $\dfrac{SF_i \times C \times ED \times EF \times IR_{air} \times (1/PEF)}{AT \times BW \times 365\ days/yr}$
inhala-
tion of
particulates

The noncancer HQ from particulate inhalation is calculated using this equation:

HQ from $=$ $\dfrac{C \times ED \times EF \times IR_{air} \times (1/PEF)}{RfD_i \times BW \times AT \times 365\ days/yr}$
inhalation
of parti-
culates

B.3   SOIL — COMMERCIAL/ INDUSTRIAL LAND USE

All three of the exposure pathways detailed below are included in the standard default equation in Section 3.2.2. If only one or some combination of these exposure pathways are of concern at a particular site, a site-specific equation can be derived.

The parameters used in the equations presented in the remainder of this section are explained in the text box below.

B.3.1   INGESTION OF SOIL

The cancer risk from ingestion of contaminated soil is calculated as follows:

Risk from $=$ $\dfrac{SF_o \times C \times 10^{-6}\ kg/mg \times EF \times ED \times IR_{soil}}{BW \times AT \times 365\ days/yr}$
ingestion
of soil

The noncancer HQ from ingestion of contaminated soil is calculated as follows:

HQ from $=$ $\dfrac{C \times 10^{-6}\ kg/mg \times EF \times ED \times IR_{soil}}{RfD_o \times BW \times AT \times 365\ days/yr}$
ingestion
of soil

B.3.2   INHALATION OF VOLATILES

The cancer risk caused by inhalation of volatiles released from contaminated soil is:

Risk from $=$ $\dfrac{SF_i \times C \times ED \times EF \times IR_{air} \times (1/VF)}{AT \times BW \times 365\ days/yr}$
inhalation
of volatiles

The equation for calculating the noncancer HQ from inhalation of volatiles released from soil is:

HQ from $=$ $\dfrac{C \times ED \times EF \times IR_{air} \times (1/VF)}{RfD_i \times BW \times AT \times 365\ days/yr}$
inhalation
of volatiles

Note that the VF value has been developed specifically for these equations; it may not be applicable in other technical contexts.

PARAMETERS FOR SOIL — COMMERCIAL/INDUSTRIAL LAND USE

Parameter	Definition	Default Value
C	chemical concentration in soil (mg/kg)	—
SF_i	inhalation cancer slope factor $((mg/kg\text{-}day)^{-1})$	chemical-specific
SF_o	oral cancer slope factor $((mg/kg\text{-}day)^{-1})$	chemical-specific
RfD_o	oral chronic reference dose (mg/kg-day)	chemical-specific
RfD_i	inhalation chronic reference dose (mg/kg-day)	chemical-specific
BW	adult body weight (kg)	70 kg
AT	averaging time (yr)	70 yr for cancer risk
		30 yr for noncancer HI (equal to ED)
EF	exposure frequency (days/yr)	250 days/yr
ED	exposure duration (yr)	25 yr
IR_{air}	workday inhalation rate (m³/day)	20 m³/day
IR_{soil}	soil ingestion rate (mg/day)	50 mg/day
VF	soil-to-air volatilization factor (m³/kg)	chemical specific (see Section 3.3.1)
PEF	particulate emission factor (m³/kg)	4.63×10^{9} m³/kg (see Section 3.3.2)

B.3.3 INHALATION OF PARTICULATES

Cancer risk due to inhalation of contaminated soil particulates is calculated as:

$$\text{Risk from inhalation of particulates} = \frac{SF_i \times C \times ED \times EF \times IR_{air} \times (1/PEF)}{AT \times BW \times 365 \text{ days/yr}}$$

The noncancer HQ from particulate inhalation is calculated using this equation:

$$\text{HQ from inhalation} = \frac{C \times ED \times EF \times IR_{air} \times 1/PEF}{RfD_i \times BW \times AT \times 365 \text{ days/yr}}$$

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

DEC 13 1991

MEMORANDUM

SUBJECT: Transmittal of Human Health Evaluation Manual, Part C:
          Risk Evaluation of Remedial Alternatives.

FROM: Henry L. Longest II, Director
          Office of Emergency and Remedial Response

          Bruce Diamond, Director
          Office of Waste Programs Enforcement

TO: Regional Waste Management Division Directors

Purpose

     This directive transmits the Risk Assessment Guidance for
Superfund, Human Health Evaluation Manual, Part C-Risk Evaluation
of Remedial Alternatives.   The guidance is to be used in the
feasibility study and selection of remedy process and supplements
the Human Health Evaluation Manual Part A--Baseline Risk
Assessment, and Part B--Development of Risk-Based Preliminary
Remediation Goals.

Background

     Section 121 of CERCLA requires an evaluation of short-term and
long-term risks associated with remedial alternatives.   In
September 1990, a Workgroup was formed to discuss the development
and use of this risk information in the remedy selection process.
The interim guidance being distributed today incorporates comments
on drafts of the guidance which were received from Headquarters and
Regional management.

Objective

     The objective of the guidance is to assist remedial project
managers, site engineers, risk assessors and others in developing
and using risk information to evaluate remedial alternatives during
the feasibility study. As you know, this evaluation compares the

risk-based benefits of alternatives, investigates potential exposures to the communities and remediation workers during the implementation of the alternative, determines the need for engineering controls to mitigate risks, and assesses the need for a five year review. The guidance will also be useful to those who seek to evaluate risks of the selected remedy during and after its implementation. Part C of the guidance will ensure consistent development and use of risk information at these important decision points in the Superfund process.

Implementation

This document is being distributed as interim guidance pending review of the RAGS series by the Science Advisory Board (SAB). It is our intention to begin updating and consolidating the series in FY 92. At that time, we will incorporate SAB's comments and the results of ongoing, EPA-sponsored research projects. We also strongly urge RPMs and Regional risk assessors to contact the Toxics Integration Branch of the Office of Emergency and Remedial Response (FTS 260-9486) with any suggestions for further improvement.

Attachment

cc: Regional Branch Chiefs
    Regional Section Chiefs
    Regional Toxics Integration Coordinators
    Workgroup Members

Risk Assessment Guidance for Superfund: Volume I — Human Health Evaluation Manual (Part C, Risk Evaluation of Remedial Alternatives)

Interim

Office of Emergency and Remedial Response
U.S. Environmental Protection Agency
Washington, DC 20460

NOTICE

The policies set out in this document are intended solely as guidance; they are not final U.S. Environmental Protection Agency (EPA) actions. These policies are not intended, nor can they be relied upon, to create any rights enforceable by any party in litigation with the United States. EPA officials may decide to follow the guidance provided in this document, or to act at variance with the guidance, based on an analysis of specific site circumstances. The Agency also reserves the right to change this guidance at any time without public notice.

This guidance is based on policies in the Final Rule of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), which was published on March 8, 1990 (55 *Federal Register* 8666). The NCP should be considered the authoritative source.

CONTENTS

CONTENTS (Continued)

EXHIBITS

DEFINITIONS

Term	Definition
Applicable or Relevant and Appropriate Requirements (ARARs)	"Applicable" requirements are those clean-up standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) site. "Relevant and appropriate" requirements are those clean-up standards which, while not "applicable" at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well-suited to the particular site. ARARs can be action-specific, location-specific, or chemical-specific.
Exposure Pathway	The course a chemical or physical agent takes from a source to an exposed organism. An exposure pathway describes a unique mechanism by which an individual or population is exposed to chemicals or physical agents at or originating from a site. Each exposure pathway includes a source or release from a source, an exposure point, and an exposure route. If the exposure point differs from the source, a transport/exposure medium (e.g., air) or media (in cases of intermedia transfer) also would be indicated.
Exposure Point	A location of potential contact between an organism and a chemical or physical agent.
Exposure Route	The way a chemical or physical agent comes in contact with an organism (i.e., by ingestion, inhalation, dermal contact).
Final Remediation Levels	Chemical-specific clean-up levels that are documented in the Record of Decision (ROD). They may differ from preliminary remediation goals (PRGs) because of modifications resulting from consideration of various uncertainties, technical and exposur factors, and all nine selection-of-remedy criteria outlined in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP).
Long-term Risks	Risks that remain after remedy implementation is complete (i.e., residual risks).
Preliminary Remediation Goals (PRGs)	Initial clean-up goals that (1) are protective of human health and the environment and (2) comply with ARARs. They are developed early in the process based on readily available information and are modified to reflect results of the baseline risk assessment. They also are used during analysis of remedial alternatives in the remedial investigation/feasibility study (RI/FS).

DEFINITIONS (Continued)

Term	Definition
Remedial Alternative	An action considered in the feasibility study intended to reduce or eliminate significant risks to human health and/or the environment at a site. A range of remedial alternatives are considered in detail by the FS while the selection of a specific remedial alternative over others is documented in the ROD.
Remedial Action	The selected alternative that is documented in the ROD.
Risk-based Concentrations	Concentration levels for individual chemicals that correspond to a specific cancer risk level (e.g., 10^{-6}, 10^{-4}) or hazard quotient (HQ) or hazard index (HI) (e.g., less than or equal to 1). They are generally selected as preliminary or final remediation goals when ARARs are not available.
Short-term Risks	Risks that occur during implementation of a remedial alternative. Some "short-term" risks can occur over a period of many years (e.g., risk associated with air stripper emissions).

ACRONYMS/ABBREVIATIONS

Acronym/ Abbreviation	Definition
ACGIH	American Conference of Governmental Industrial Hygienists
AIC	Acute Inhalation Criteria
APCD	Air Pollution Control Device
ARARs	Applicable or Relevant and Appropriate Requirements
ATSDR	Agency for Toxic Substances and Disease Registry
CEGL	Continuous Exposure Guidance Level
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
ECAO	Environmental Criteria and Assessment Office
EEGL	Emergency Exposure Guidance Level
EPA	U.S. Environmental Protection Agency
HEAST	Health Effects Assessment Summary Tables
HHEM	Human Health Evaluation Manual
HI	Hazard Index
HQ	Hazard Quotient
IDLH	Immediately Dangerous to Life and Health
IRIS	Integrated Risk Information System
LOAEL	Lowest-observed-adverse-effect-level
MCL	Maximum Contaminant Level
MRL	Minimal Risk Level
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NIOSH	National Institute for Occupational Safety and Health
NOAEL	No-observed-adverse-effect-level
NRC	National Research Council

Acronym/Abbreviation	Definition
ORD	Office of Research and Development
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Level
POTW	Publicly Owned Treatment Works
PPE	Personal Protective Equipment
PRG	Preliminary Remediation Goal
QA/QC	Quality Assurance/Quality Control
RAGS	Risk Assessment Guidance for Superfund
RCRA	Resource Conservation and Recovery Act
REL	Recommended Exposure Level
RfC	Reference Concentration
RfD	Reference Dose
RI/FS	Remedial Investigation/Feasibility Study
RME	Reasonable Maximum Exposure
ROD	Record of Decision
RPM	Remedial Project Manager
RQ	Reportable Quantity
RREL	Risk Reduction Engineering Laboratory
SARA	Superfund Amendments and Reauthorization Act
SPEGL	Short-term Public Emergency Guidance Level
TLV-C	Threshold Limit Values - Ceiling
TLV-STEL	Threshold Limit Values - Short-term Exposure Limit
TLV-TWA	Threshold Limit Values - Time-weighted Average
TSC	Superfund Health Risk Technical Support Center

PREFACE

Risk Assessment Guidance for Superfund: Volume I — Human Health Evaluation Manual (RAGS/HHEM) Part C is one of a three-part series. Part A addresses the baseline risk assessment; Part B addresses the development of risk-based preliminary remediation goals. Part C provides guidance on the human health risk evaluations of remedial alternatives that are conducted during the feasibility study, during selection and documentation of a remedy, and during and after remedy implementation. Part C provides general guidance to assist in site-specific risk evaluations and to maintain flexibility in the analysis and decision-making process. This guidance does not discuss the evaluation of ecological effects that takes place during remedy selection and implementation, nor does it discuss the risk management decisions that are necessary at a CERCLA site (e.g., selection of final remediation goals). The potential users of Part C are persons involved in the remedy selection and implementation process, including risk assessors, risk assessment reviewers, remedial project managers, and other decision-makers.

This manual is being distributed as an interim document to allow for a period of field testing and review. RAGS/HHEM will be revised in the future, and Parts A, B, and C will be incorporated into a single final guidance document. Additional information for specific subject areas is being developed for inclusion in a later revision. These areas include:

- development of short-term inhalation toxicity values;
- short-term worker health and safety issues; and
- determination of attainment of final remediation goals.

Comments addressing usefulness, changes, and additional areas where guidance is needed should be sent to:

> U.S. Environmental Protection Agency
> Toxics Integration Branch (OS-230)
> Office of Emergency and Remedial Response
> 401 M Street, SW
> Washington, DC 20460
>
> Telephone: 202-260-9486
> FAX: 202-260-6852

CHAPTER 1

INTRODUCTION

This guidance has been developed by the U.S. Environmental Protection Agency (EPA) to assist remedial project managers (RPMs), risk assessors, site engineers, and others in using risk information at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites to both evaluate remedial alternatives during the feasibility study (FS) and to evaluate the human health risk associated with the selected remedial alternative during and after its implementation. Part C provides general guidance to assist in site-specific risk evaluations and to maintain flexibility in the decision-making process.

Risk assessment is one of many tools that RPMs use in selecting the best remedy for a site. Other important tools (not addressed in this guidance) involve the assessments of technical feasibility, applicable or relevant and appropriate requirements (ARARs), cost, and implementability.

This guidance is the third part (Part C) in the series *Risk Assessment Guidance for Superfund: Volume I — Human Health Evaluation Manual* (RAGS/HHEM). Part A of this guidance (EPA 1989g) describes how to conduct a site-specific baseline risk assessment; the information in Part A is necessary background for Part C. Part B (EPA 1991c) provides guidance for calculating risk-based concentrations that may be used, along with ARARs and other information, to develop preliminary remediation goals (PRGs) during project scoping. PRGs (and final remediation levels set in the Record of Decision [ROD]) can be used throughout the analyses in Part C to assist in evaluating the human health risks of remedial alternatives. Exhibit 1-1 illustrates the major correspondence of RAGS/HHEM activities with the steps in the CERCLA remedial process.

The steps for conducting a risk evaluation of remedial alternatives are discussed in general terms in Chapters 2 and 3; more detailed guidance for conducting short-term evaluations is provided in Appendices A through D. (See the box in the next column for a description of how the terms short-

term risk and long-term risk differ in this guidance.) The remainder of this chapter:

- presents the scope and an overview of Part C;

- discusses the statutes, regulations, and guidance relevant to the evaluation of remedial alternatives;

- describes appropriate levels of effort for risk evaluations of remedial alternatives;

- discusses the importance of risk communication;

- addresses the role of the RPM and the need for documentation; and

- presents the organization of the remainder of this document.

1.1 SCOPE AND OVERVIEW OF PART C

1.1.1 SCOPE

As discussed in Section 1.2 below, some of the nine criteria that are described in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) and that are used to evaluate remedial alternatives during the remedial investigation feasibility study (RI/FS), involve a direct use of risk-related information. Several aspects of these criteria (e.g., short-term risks to workers and

EXHIBIT 1-1

RELATIONSHIP OF THE HUMAN HEALTH EVALUATION
TO THE CERCLA PROCESS

CERCLA REMEDIAL PROCESS

| Scoping | → | Remedial Investigation / Feasibility Study | → | Remedy Selection and Record of Decision | → | Remedial Design/ Remedial Action | → | Deletion/ Five-year Review |

HUMAN HEALTH EVALUATION MANUAL

PART A
Baseline Risk Assessment

PART B
Development of Risk-based
Preliminary Remediation Goals

PART C
Risk Evaluation of Remedial Alternatives
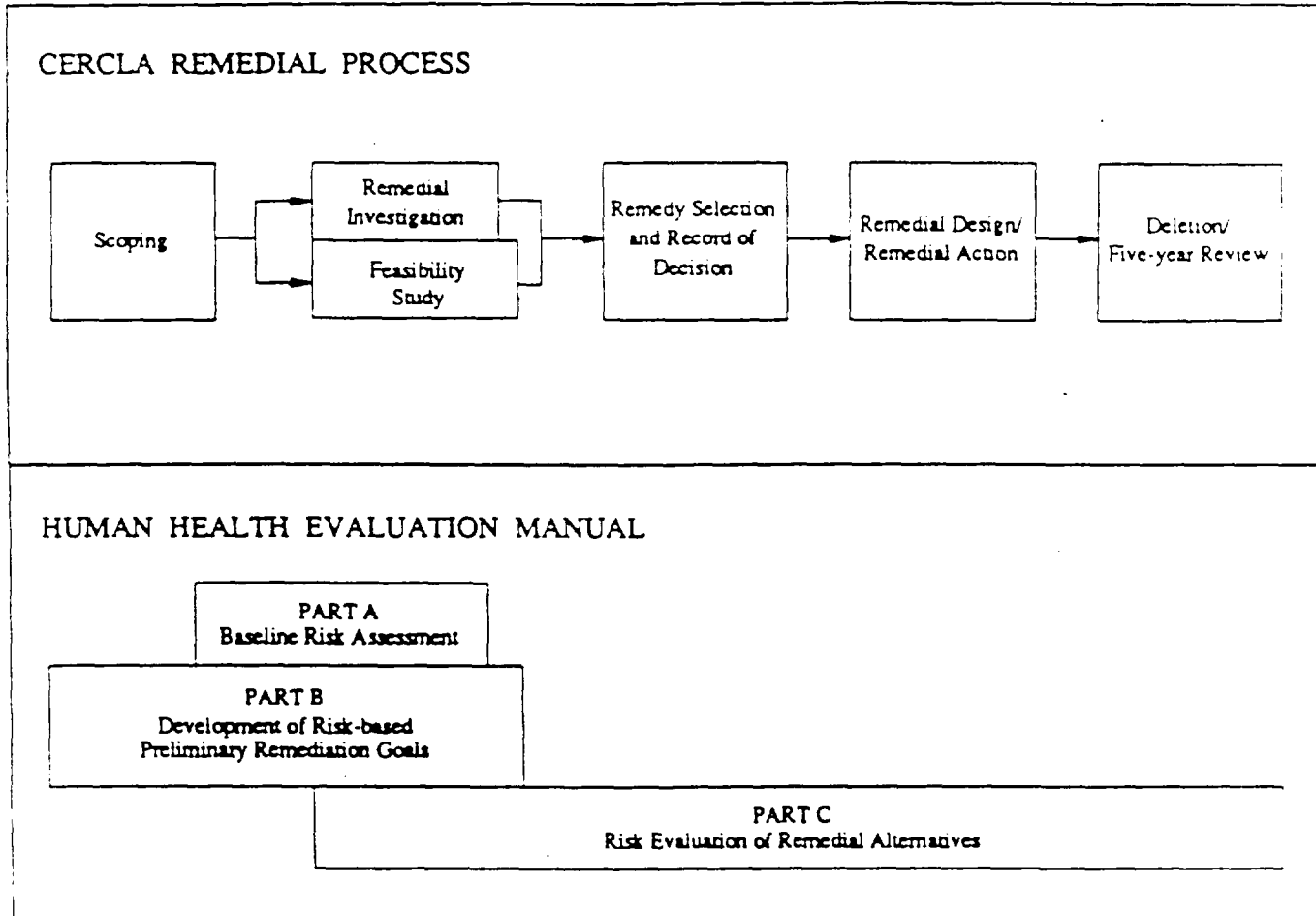
surrounding community. long-term effectiveness) are discussed in detail in this guidance. Other criteria that do not directly involve health risk (e.g., implementability, cost) — with the exception of community acceptance — are mentioned briefly but are not discussed in detail.

Remedial alternatives, in addition to being evaluated for the degree to which they protect human health, are evaluated for their potential to protect ecological receptors. RAGS/HHEM Part C does not address ecological risk assessment (see the next box). However, ecological guidance specific to evaluating remedial alternatives in the CERCLA program will be developed following finalization of Agency guidance on ecological risk assessment.

EVALUATING ECOLOGICAL EFFECTS OF REMEDIAL ALTERNATIVES

Remedial actions, by their nature, can alter or destroy aquatic and terrestrial habitat. This potential for destruction or alteration of habitat and subsequent consequences must be evaluated so that it can be considered during the selection of a remedial alternative and during its implementation.

This document does not address the evaluation of ecological risks. Future guidance for ecological evaluations is planned, however. At present, ecological evaluations should be based on the best professional judgment of experienced ecologists and/or aquatic or environmental toxicologists.

The guidance in this document applies to sites contaminated with non-radioactive hazardous substances and those contaminated with radionuclides. Appendix D provides additional guidance specific to radionuclide sites.

Note that this guidance is limited to the use of risk assessment in evaluating remedial alternatives. Part C does not provide guidance on the risk management decisions that must be made when evaluating alternatives and selecting a remedy (e.g., balancing of the nine NCP criteria, selection of final remediation goals and levels) or engineering judgments that affect the evaluation of alternatives (e.g., determining whether an alternative is likely to achieve remediation goals). These issues are addressed in other guidance or in guidance that currently is being developed.

1.1.2   OVERVIEW

The process of evaluating remedial alternatives begins in the development and screening stage of the FS and extends into the detailed analysis stage. The major goal for the risk evaluation during these steps is to provide decision-makers with specific information that they may need in choosing among alternatives. Additional risk evaluations may need to be conducted during the proposed plan, during the design and implementation of the remedy, and after the remedy is complete (e.g., during "five-year reviews"). These activities are discussed below and throughout this guidance.

Exhibit 1-2 summarizes the levels of effort and purposes of the risk evaluations of remedial alternatives, while Exhibit 1-3 illustrates when these activities take place within the context of the CERCLA remedial process.

Identification and Screening of Technologies and Alternatives. During this stage, a range of remedial alternatives is identified, if necessary, and each alternative is evaluated with respect to effectiveness, implementability, and cost. This process may consist of two steps: (1) identification and screening of technologies and (2) development and screening of alternatives. These steps are often combined into a single step (as reflected in this guidance). Those alternatives that are clearly unfavorable relative to other alternatives in terms of effectiveness (e.g., very high perceived risk) or implementability, or that are grossly excessive in cost are dropped from consideration after this screening. Part of the evaluation of effectiveness involves human health risk (e.g., risks to the community and remediation workers), and Chapter 2 of this document provides guidance on evaluating these factors. RAGS/HHEM Part C does not discuss evaluating factors such as implementability and cost.

Detailed Analysis of Alternatives. During the detailed analysis stage, alternatives are evaluated according to each of the nine NCP evaluation criteria, and then are compared to each other. Both long-term effectiveness (i.e., residual risk) and short-term effectiveness (i.e., risk to the community and remediation workers during remedy implementation) are evaluated during the detailed analysis. Chapter 2 and Appendices A

EXHIBIT 1-2

SUMMARY OF RISK EVALUATIONS OF REMEDIAL ALTERNATIVES

STAGE	LEVEL OF EFFORT[*]		PRIMARY PURPOSE OF RISK EVALUATION[b]	
	Short-term Risk[c]	Long-term Risk	Short-term Risk[c]	Long-term Risk
Screening of Alternatives (Section 2.1)	Qualitative	Qualitative	Identify (and eliminate from consideration) alternatives with clearly unacceptable short-term risks.	Identify (and eliminate from consideration) alternatives with clearly unacceptable long-term risks.
Detailed Analysis of Alternatives (Section 2.2)	Qualitative or Quantitative[d]	Qualitative or Quantitative[d]	Evaluate short-term risks of each alternative to community and on-site remediation workers during implementation so that these risks can be compared among alternatives.	Evaluate long term (residual) risk of each alternative and its ability to provide continued protection over time so that these risks can be compared among alternatives.
Proposed Plan (Section 3.1)	Qualitative or Quantitative[d]	Qualitative or Quantitative[d]	Refine previous analyses, as needed, based on newly developed information.	Refine previous analyses, as needed, based on newly developed information.
Record of Decision (Section 3.2)	Qualitative or Quantitative[d]	Qualitative or Quantitative[d]	Document short-term risks that may occur during remedy implementation.	Document risks that may remain after completion of remedy and determine need for five-year reviews.
Remedial Design (Section 3.3)	Qualitative or Quantitative[d]	Qualitative or Quantitative[d]	Refine previous analyses, as needed, and identify need for engineering controls or other measures to mitigate risks.	Refine previous analyses, as needed, and identify need for engineering controls or other measures to mitigate risks.
Remedial Action (Section 3.3)	Quantitative	Quantitative	Ensure protection of workers and community by monitoring emissions or exposure concentrations, as needed.	Evaluate whether remediation levels specified in ROD have been attained and evaluate residual risk after completion of remedy to ensure protectiveness.
Five-year Review (Section 3.4)	Generally not applicable	Quantitative	Generally not applicable.	Confirm that remedy (including any engineering or institutional controls) remains operational and functional and evaluate whether clean-up standards are still protective.

[a] Level of effort (i.e., qualitative or quantitative) refers only to the level of risk evaluation that is generally expected. Levels other than those presented here, or combinations of levels, are possible. See the main text of this document for additional discussion on level of effort.

[b] Purpose presented in this exhibit for each stage is only the primary purpose; other purposes may exist. See the main text of this document for additional information.

[c] Short-term risk refers to risks that occur during remedy implementation.

[d] Section 2 conditions decide whether a qualitative or quantitative risk evaluation is needed for these stages.

EXHIBIT 1-3

RISK EVALUATION OF REMEDIAL ALTERNATIVES IN THE
CERCLA PROCESS

STAGES IN REMEDIATION

```
┌──────────────┐
│  Remedial    │
│ Investigation│───┐
└──────────────┘   │        ┌──────────────┐      ┌──────────────────┐      ┌──────────────────┐
                   ├───────▶│ Selection of │─────▶│ Remedial Design/ │────▶│   Deletion/      │
┌──────────────┐   │        │   Remedy     │      │ Remedial Action  │      │ Five-year Review │
│ Feasibility  │───┘        └──────────────┘      └──────────────────┘      └──────────────────┘
│   Study      │
└──────────────┘
```

STAGES IN EVALUATING REMEDIAL ALTERNATIVES

```
                                                          ┌──────────────────┐
                                                          │  Evaluate Risks  │      ┌──────────────────┐
                                                          │ During Remedial  │      │    Revisit       │
                                                          │ Design/Remedial  │─────▶│ Protectiveness   │
┌──────────────┐      ┌──────────────────┐               │    Action        │      └──────────────────┘
│Evaluate Risks│      │ Develop Proposed │          ┌───▶└──────────────────┘
│During Screening│    │    Plan and      │          │
│ and Detailed │─────▶│ Document Risks   │──────────┤
│ Analysis of  │      │ of Alternatives  │          │    ┌──────────────────────┐
│ Alternatives │      │ in Record of     │          │    │Evaluate Attainment of│
└──────────────┘      │   Decision       │          └───▶│  Final Goals and     │
                      └──────────────────┘               │   Residual Risk      │
                                                          └──────────────────────┘
```

through D of this document provide guidance on the evaluation of the risk-related aspects of long-term effectiveness (residual risk and permanence), and short-term effectiveness. (As with the screening of alternatives, Chapter 2 generally does not discuss evaluation of the other criteria, which do not directly involve human health risk considerations.) The resulting risk information is incorporated into the overall detailed analysis process described in the *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (RI/FS Guidance; EPA 1988c).

Proposed Plan and ROD. Risk evaluations are generally conducted during the development of the proposed plan and ROD only when new information concerning risks of the remedial alternatives is generated. Chapter 3 provides guidance on the evaluation of risks for the proposed plan and ROD stage.

Remedial Design/Remedial Action (RD/RA). Risk-related evaluations may also be conducted for some sites during implementation of the selected remedy. These activities, discussed briefly in Chapter 3, include: (1) refining risk evaluations as necessary when designing the remedy; (2) monitoring potential short-term health impacts on the community and workers; (3) assessing attainment of final remediation levels selected in the ROD; and (4) evaluating residual risk.

Five-year Review. Under the NCP, five-year reviews are required for sites as long as hazardous substances remain onsite above levels that allow unlimited use and unrestricted exposure, and are also conducted as a matter of policy for long-term remedial action sites even if no hazardous substances are expected to remain after completion of the action. Chapter 3 briefly addresses the consideration of risk during five-year reviews.

1.2 RELEVANT STATUTES, REGULATIONS, AND GUIDANCE

As discussed in RAGS/HHEM Part A, there is a hierarchy of requirements and guidance in CERCLA, beginning with the laws enacted by Congress, followed by the regulations, and then the guidance developed by EPA. This section addresses this hierarchy within the context of the risk evaluation of remedial alternatives.

1.2.1 CERCLA/SARA

CERCLA, commonly called Superfund, was enacted by Congress in 1980 in response to the dangers posed by sudden or otherwise uncontrolled releases of hazardous substances, pollutants, or contaminants into the environment. The Superfund Amendments and Reauthorization Act (SARA) was enacted in 1986. (All references to CERCLA in this guidance should be interpreted as "CERCLA as amended by SARA.")

Section 121 of CERCLA requires that remedies be protective of human health and the environment, satisfy ARARs, be cost-effective, and utilize permanent solutions and alternative treatment technologies to the maximum extent practicable. Section 121(c) of CERCLA requires a periodic review of remedial actions, at least every five years after initiation, for as long as hazardous substances that may pose a threat to human health or the environment remain at the site. The information in this manual provides guidance for evaluating the protectiveness of remedial alternatives at a site in terms of the human health-related aspects of these CERCLA requirements. Some considerations include protectiveness, effectiveness in terms of risk reduction, and degree of hazard for substances remaining at the site.

1.2.2 NCP

The NCP is the main set of regulations developed by EPA to implement CERCLA. The most recent NCP was published on March 8, 1990 (55 *Federal Register* 8666-8865) and is codified at 40 *Code of Federal Regulations* (CFR) Part 300. Section 300.430(e)(1) of the NCP describes a two-stage evaluation of remedial alternatives: a screening evaluation of a range of alternatives, if necessary, followed by a detailed analysis of the most promising alternatives. The NCP also describes activities that follow selection and implementation of the selected remedial alternative.

Screening. NCP section 300.430(e)(7) indicates that, if necessary and to the extent sufficient information is available, alternatives should be screened out if determined to be ineffective, not implementable, or grossly excessive in cost. Some aspects of effectiveness involve considerations of human health risk and are discussed in this guidance.

Detailed Analysis. The NCP establishes nine criteria in section 300.430(e)(9)(iii) to use in evaluating alternatives in detail and in selecting a remedy. Parts of three of these criteria — overall protection of human health and the environment, long-term effectiveness and permanence, and short-term effectiveness — directly relate to risks and therefore are the focus of this guidance. The actual selection of a remedy for any given site ultimately is based on consideration of the nine criteria. This guidance also discusses the importance of risk communication to the community as it relates to the criterion of community acceptance.

Five-year Reviews. NCP section 300.430(f)(4)(ii) provides that if a remedial alternative is selected that results in hazardous substances (or pollutants or contaminants) remaining at the site above levels that allow for unrestricted exposure and unlimited use, such remedy should be reviewed at least every five years after initiation of the selected remedial alternative.

1.2.3 OTHER RELEVANT GUIDANCE

Three CERCLA program documents are important background for the guidance presented in this document — RAGS/HHEM Parts A and B (EPA 1989g; EPA 1991c), and the RI/FS Guidance (EPA 1988c). Parts A and B provide guidance on conducting a baseline risk assessment and on developing risk-based concentrations, respectively, that should be used in evaluating remedial alternatives. The activities conducted during a risk evaluation of remedial alternatives are somewhat similar to the activities conducted during a baseline risk assessment. (Chapter 2 discusses in more detail the similarities and differences.) The RI/FS Guidance describes the major activities and analyses that are conducted during the RI/FS. See the references at the end of this document for other relevant background guidance.

1.3 LEVEL OF EFFORT

The level of effort for risk evaluations of remedial alternatives depends primarily on the site-specific questions that must be answered in order to select and implement a remedy. In addition, site-specific factors such as the complexity of the site, the number of alternatives considered for the site, the available resources, and the amount of available data may affect the level of effort. In most cases, a qualitative rather than a detailed

quantitative evaluation of both long-term and short-term risks is all that is needed to select the most appropriate alternative. A quantitative risk evaluation of remedial alternatives will not need to be conducted for all sites. In all cases, the baseline risk assessment provides much of the risk-related information needed for the detailed analysis of alternatives, especially for those alternatives that involve limited or no action.

For many sites, the risk evaluations of remedial alternatives during the FS are conducted in a qualitative manner. That is, the risk evaluations during both the screening and detailed analysis stages for these sites will not be at all quantitative. At other sites, a more quantitative analysis of the long-term and/or short-term risks associated with the remedial alternatives may be needed during the detailed analysis. In these situations, the risk evaluation generally needs to incorporate more site-specific information.

A guiding principle is that the risk evaluation should be tailored to provide the RPM with specific information that he or she needs for supporting the selection or design of a remedy (e.g., the relative risks associated with alternatives, the alternatives that best meet the remediation goals). Because of the differences in information needs and available data for sites, in the complexity of sites, and in available methods, models, and resources for evaluation, all of the components of this guidance will not be applicable to all sites.

Chapter 2 provides some additional factors to consider when deciding on the level of effort to use for the risk evaluation of remedial alternatives.

1.4 IMPORTANCE OF RISK COMMUNICATION

As noted earlier, while overall protection of human health and the environment is one of the threshold criteria established by the NCP for use in evaluating alternatives and selecting a remedy, community acceptance of the remedy is a modifying criterion (NCP section 300.430(e)(9) (iii)). The CERCLA program encourages and promotes public participation during all phases of the decision-making process at CERCLA sites. Just as risk information is used by RPMs and other EPA staff to assist in evaluation of remedial alternatives during the FS and to evaluate the selected remedial alternative during and after its

implementation, risk information also will be employed by the public in their acceptance of a selected remedy. Good communication of the risks of the remedy to the public is crucial to the community's acceptance of the remedy.

There is no single procedure for good risk communication. The actual mechanism used and the messages delivered will vary from site to site and will depend upon the public, their level of concern, the complexity of the site, the contaminants of concern, and the proposed remedial alternative. RPMs are encouraged to work with the risk assessor and community relations coordinator for the site to develop the appropriate means to communicate risks from the remedial alternative or any residual risks. RPMs should consider using fact sheets, public meetings, and the release of draft documents or "risk communication" summaries as vehicles for risk communication. *Community Relations in Superfund: A Handbook* (EPA 1988a) offers guidance on planning and conducting CERCLA community relations activities.

Regardless of the vehicles chosen for risk communication, the following rules, from *Seven Cardinal Rules of Risk Communication* (EPA 1988f), should be kept in mind.

- Accept and involve the public as a legitimate partner.

- Plan carefully and evaluate your efforts.

- Listen to the public's specific concerns.

- Be honest, frank, and open.

- Coordinate and collaborate with other credible sources.

- Meet the needs of the media.

- Speak clearly and with compassion.

As provided under the NCP, risk communication, public participation, and community relations at CERCLA sites begin well before the remedy selection phase. This is important, as communities near CERCLA sites may begin with a degree of outrage that must be addressed before effective communication can begin. Community relations, public involvement, and good risk communication continue throughout

the RI FS process. A well-informed public will be better able to comment on — and provide input to — technical decisions. Establishing credibility through community relations, public participation, and effective risk communication practices early in the CERCLA process leads to greater community acceptance of the selected remedy.

1.5 MANAGEMENT AND DOCUMENTATION

One role of an RPM in the risk evaluation of remedial alternatives is to make risk management decisions. The RPM must have a comprehensive understanding of the risk evaluation in order to make these decisions. The first box on the next page provides questions that RPMs and other decision-makers should ask about the risks of remedial alternatives at their sites. The second box provides guidance on where to document the evaluations addressed in RAGS/HHEM Part C.

1.6 ORGANIZATION OF THE DOCUMENT

The remainder of this guidance is organized into two additional chapters and four appendices. as follows:

- Chapter 2: Risk Evaluation During the Feasibility Study;

- Chapter 3: Risk Evaluation After the Feasibility Study;

- Appendix A: Selected Remediation Technologies and Associated Potential Releases;

- Appendix B: Guidance for Quantifying Potential Releases from Selected Remediation Technologies;

- Appendix C: Short-term Toxicity Values; and

- Appendix D: Radiation Remediation Technologies.

In addition, several boxes, such as those below, provide useful information. A second kind of box, a "shadow" box, provides case studies. These boxes are presented at the end of Chapter 2.

QUESTIONS RPMs SHOULD ASK ABOUT HUMAN HEALTH RISKS OF REMEDIAL ALTERNATIVES

- Which technologies can readily achieve all preliminary remediation goals (PRGs) in a given medium? What uncertainties are involved in this determination?

- Which alternatives will clearly not address the significant human exposure pathways identified in the baseline risk assessment?

- Are the expected residual risks or short-term risks from one alternative significantly different from another?

- What other risk-based benefits (e.g., shorter time to achieving goals) are realized by selecting one alternative over another?

- Will implementation of specific technologies create new chemicals of concern or new significant exposures or risks for the surrounding community?

- Is there a need for engineering controls or other measures to mitigate risks during implementation? Are such controls available? How reliable are these controls?

- Does the remedial alternative result in hazardous substances remaining at the site such that a five-year review or reviews would be required?

DOCUMENTATION OF RISK EVALUATIONS

- The risk evaluation conducted during the development and screening of alternatives (Section 2.1) and during the detailed analysis of alternatives (Section 2.2) should be documented in the FS.

- The proposed plan (Section 3.1) should contain a summary of the risk evaluations for the alternatives, including any new risk information identified during development of the proposed plan.

- The ROD (Section 3.2) should contain the results of the risk evaluations of the alternatives and the preferred alternative, including any results developed since the proposed plan.

- Any significant changes identified during RD/RA (Section 3.3) in the risk evaluations should be documented (e.g., in a memorandum).

- Each five-year review (Section 3.4) should contain a statement on protectiveness and, if necessary, a recalculation of risk and/or a new risk assessment.

CHAPTER 2

RISK EVALUATION DURING THE FEASIBILITY STUDY

The FS generally is a two-step process of evaluating remedial alternatives: (1) screening, if necessary, and (2) a more detailed analysis for those alternatives that pass the screening. The RI·FS Guidance provides information on conducting the FS and describes all of the evaluations that are performed. Some of these evaluations pertain to human health risk, and the guidance in this chapter assists in these evaluations. (Ecological effects of remedial alternatives — not discussed in RAGS·HHEM Part C — also must be considered during the FS.)

2.1 RISK EVALUATION DURING DEVELOPMENT AND SCREENING OF ALTERNATIVES

The overall objective of the development and screening of alternatives is to identify an appropriate range of waste management options, some of which will be analyzed more fully in the detailed analysis phase. This process usually takes place relatively early in the RI/FS process, during project scoping (before the baseline risk assessment is completed).

The NCP specifies that the long-term and short-term aspects of three criteria — effectiveness, implementability, and cost — should be used to guide the development and screening of remedial alternatives. At screening, those alternatives that are clearly unacceptable in terms of effectiveness or implementability or are grossly excessive in cost may be eliminated from further consideration.

Consideration of effectiveness involves evaluating the long-term and short-term human health risks — among other factors — associated with a remedial alternative. The criteria of implementability and cost are not related to risk and, therefore, are not discussed in this document.

2.1.1 CONSIDERATION OF LONG-TERM HUMAN HEALTH RISKS

The long-term human health risks associated with a remedial alternative are those risks that will remain after the remedy is complete (i.e., residual risks). Evaluating long-term risks might ideally include an assessment of the risks associated with treatment residuals and untreated wastes (for a treatment-based remedy), or an evaluation of the remedy's ability to provide protectiveness over time (for a containment-based remedy). This approach might simply involve comparing estimates of the final concentrations that a remedy is expected to achieve in a medium with the PRGs for those chemicals in that medium. At the screening stage, however, this evaluation typically is based on professional judgment and the experience of the CERCLA program staff. Quantifying residual risks during screening generally is not necessary. For example, a technology may be evaluated during screening for its potential to treat the classes — or treatability groups — of chemicals present at the site (e.g., volatile organics, halogenated organics, non-volatile metals) rather than its ability to meet chemical-specific PRGs. See Section 2.2.1 for additional information on long-term risks associated with remedial alternatives.

2.1.2 CONSIDERATION OF SHORT-TERM HUMAN HEALTH RISKS

The short-term human health risks associated with a remedial alternative are those risks that occur during implementation of the remedial alternative (e.g., risks associated with emissions from an onsite air stripper). Because some remedies may take many years to complete, some "short-term" risks may actually occur over a period of many years. Populations that may be exposed to chemicals during remedy implementation include: (1) people who live and work in the vicinity of the site and (2) workers who are involved in site remediation. As with the consideration of long-term risks, this evaluation is based primarily on

many simplifying assumptions and on professional judgment at the screening stage and is intended to identify alternatives with clearly unacceptable short-term risks. See Section 2.2.2 and Appendices A and D for additional information on evaluating alternatives for short-term risks during screening and development of alternatives.

2.2 RISK EVALUATION DURING DETAILED ANALYSIS OF ALTERNATIVES

The overall objective of the detailed analysis of alternatives is to obtain and present the information that is needed for decision-makers to select a remedial alternative for a site. This detailed analysis usually takes place during the later stages of the RI/FS process (i.e., near the end of or after the baseline risk assessment, when PRGs may have been modified). As discussed previously, two of the balancing criteria assessed during the detailed evaluation — long-term effectiveness and short-term effectiveness — involve an evaluation of risk. In addition, these criteria are considered in evaluating the criterion of overall protection of human health and the environment.

The risk evaluations of remedial alternatives involve the same general steps as the baseline risk assessment: exposure assessment, toxicity assessment, and risk characterization. The box on this page discusses the connection between the baseline risk assessment and the risk evaluations of remedial alternatives.

The guidance provided in this section assists in assembling and using available site-specific information for the purpose of completing the detailed analysis of remedial alternatives, specifically the evaluation of criteria that pertain to human health risks. The box on the next page lists several sources of information that can be used in the risk evaluations that are conducted during the RI/FS. The box on page 14 addresses the question of whether a quantitative evaluation is needed. The case studies at the end of this chapter provide examples of a qualitative and a quantitative evaluation of long-term and short-term risks during the detailed analysis.

CONNECTION BETWEEN THE BASELINE RISK ASSESSMENT AND THE RISK EVALUATION OF REMEDIAL ALTERNATIVES

A risk evaluation of remedial alternatives follows the same general steps as a baseline risk assessment. Detailed guidance on each step is provided in RAGS/HHEM Part A, which must be reviewed and understood by the risk assessor before a risk evaluation of remedial alternatives is conducted. Note, however, that the baseline risk assessment typically is more quantitative and requires a higher level of effort than the risk evaluation of remedial alternatives. Other differences (and similarities) are listed below.

Evaluate Exposure (Part A — Chapter 6)

- The source of releases for the baseline risk assessment is untreated site contamination while the source of releases for the evaluation of remedial alternatives is the remedial action itself (plus any remaining waste).

- Exposure pathways associated with implementation of remediation technologies may include some pathways and populations that were not present (or of concern) under baseline conditions.

- The evaluation of short-term exposures associated with remedial alternatives may consider a number of different releases that occur over varying durations.

Evaluate Toxicity (Part A — Chapter 7)

- The risk evaluation of remedial alternatives often involves less-than-lifetime exposures that require appropriate short-term toxicity values to characterize risk or hazard.

- The risk evaluation of remedial alternatives may include an analysis of chemicals that were not present under baseline conditions (i.e., created as a result of the remedial alternative).

Characterize Risks (Part A — Chapter 8)

- A risk evaluation of remedial alternatives generally considers risks to onsite workers, as well as risks to the surrounding community.

- There are additional uncertainties involved in evaluating risks of remedial alternatives that are not considered in the baseline risk assessment (e.g., confidence in performance of remedies and patterns of predicted releases, confidence in attainment of clean-up levels).

SOURCES OF INFORMATION FOR RISK EVALUATIONS DURING THE FS

Baseline Risk Assessment. Much of the data collected during the baseline risk assessment can also be used to calculate the long-term residual risk associated with a remedial alternative. Some of the data may be applicable to calculation of risks during the remedial action. Some of the information from the baseline risk assessment that may be useful for analyzing the risks associated with the remedial alternative includes:

- exposure setting, including exposed populations and future land use (RAGS/HHEM Part A, Section 6.2);

- exposure pathways, including sources of contamination, chemicals of concern, fate and transport of chemicals after release, and exposure points (RAGS/HHEM Part A, Section 6.3);

- general exposure considerations, including contact rate, exposure frequency, and duration (RAGS/HHEM Part A, Section 6.4);

- exposure concentrations, including monitoring data, modeling results, and media-specific results (RAGS/HHEM Part A, Section 6.5);

- estimates of chemical intake (RAGS/HHEM Part A, Section 6.6);

- toxicity information (e.g., changes/additions to Integrated Risk Information System [IRIS] and Health Effects Assessment Summary Tables [HEAST]) (RAGS/HHEM Part A, Chapter 7);

- quantitation of risks (RAGS/HHEM Part A, Section 8.6); and

- uncertainties associated with toxicity assessment, exposure assessment, and baseline risk characterization (RAGS/HHEM Part A, Sections 6.8, 7.6, and 8.5).

Treatability Studies. Treatability investigations are site-specific laboratory or field studies, performed either with laboratory screening, bench-scale, or pilot-scale study (see Section 5.3 of the RI/FS Guidance). Generic studies for technologies (e.g., those performed by a vendor) can also contain useful information. Treatability studies may provide risk-related data such as (1) information on short-term emissions and (2) information on removal efficiencies of a technology. This information may be especially useful when considering innovative technologies. *Guide to Conducting Treatability Studies under CERCLA* (under development by EPA's Risk Reduction Engineering Laboratory) provides a three-tiered approach to conducting treatability studies during screening, selection, and design of remedial alternatives. Chapter 5 of the RI/FS Guidance, especially Section 5.6, provides information on evaluating the applicability of the treatability study results (e.g., determination of usefulness, documentation, usefulness of residual information, application of laboratory/ bench/pilot studies to full-scale system).

Feasibility Studies or Other Analyses for Comparable Sites. If a risk evaluation of one of the alternatives being considered was conducted during the FS (or later stages) for a site with similar wastes and similar conditions, some of the information that was developed may be helpful in characterizing the short-term or long-term risks associated with that alternative. This type of information should be examined carefully to determine whether the analyses are appropriate for the site currently being evaluated. Differences in the types of hazardous substances present, characteristics of environmental media, meteorological conditions, locations of receptors, or other factors could result in large differences in the risk evaluation.

The Engineering and Technical Support Center of EPA's Risk Reduction Engineering Laboratory (513-569-7406 or FTS 684-7406) can provide information concerning treatability studies and evaluations of remedial technologies.

2.2.1 EVALUATION OF LONG-TERM HUMAN HEALTH RISKS FOR DETAILED ANALYSIS

Evaluation of the long-term human health
risks associated with a remedial alternative
involves: (1) evaluating residual risk and
(2) evaluating the alternative's ability to provide
protection over time.

Evaluate Residual Risk. Because PRGs
generally are based on chronic human health risk
considerations (e.g., ARARs such as maximum
contaminant levels (MCLs), or risk-based
concentrations), they usually provide the standard
to use to evaluate long-term health risks. When
site engineers are developing alternatives and
determining whether a technology is capable of
achieving PRGs, they are in effect evaluating
residual risk. (Therefore, the results from using
RAGS/HHEM Part B and other guidance on
remediation goals are very important for this part
of the analysis.)

Most of the time it will be sufficient for the
detailed analysis to indicate whether or not an
alternative has the potential to achieve the PRGs,
rather than to quantify the risk that will remain
after implementation of the alternative. If more
detailed information concerning long-term risk is
needed to select an alternative (e.g., to determine
the more favorable of two otherwise similar
alternatives), then it may be useful to determine
whether one alternative is more certain to achieve
the PRGs than the other, whether (or to what
extent) one may be able to surpass (i.e., achieve
lower concentrations than) the PRGs, or whether
one may be able to achieve the goals in a shorter
time.

Certain remedial technologies (e.g.
incineration) may produce new contaminants that
were not present at the site under baseline
conditions. The risks associated with these
additional substances generally should be
evaluated. Another consideration in evaluating
the residual risk associated with some alternatives
is the level of confidence in the ability of the
remedy as a whole to achieve the site engineers'
predictions. For some technologies (e.g., ground-
water extraction and treatment technologies), past
experience has indicated that, in some situations,
it may be difficult or impossible to achieve the
predicted goals. This information on the

uncertainty associated with an alternative may be an important factor in selecting a remedy.

After the individual technologies comprising a remedial alternative have been examined separately, then the alternative as a whole should be examined to determine the extent to which it meets the PRGs for all of the contaminated media and all of the contaminants of concern. Even if PRGs will be met, potential cumulative effects on human health due to multiple contaminants, media, or exposures may need to be considered. If an alternative will not meet the PRGs for all media or contaminants of concern or if cumulative effects are a concern, this information should be highlighted in the presentation of the results of the detailed analysis.

Evaluate Protectiveness Over Time. Evaluating whether an alternative is likely to maintain the specified level of protectiveness over time (often referred to as "permanence") involves using expert engineering judgment. In particular, if an alternative relies on engineering or institutional controls to reduce or eliminate exposure to contaminated media, then the ability of these controls to maintain protectiveness should be considered. These types of remedies provide protection by reducing or eliminating exposure to hazardous substances rather than eliminating the hazardous substances or reducing their concentrations, volumes, or toxicity. Failure of such remedies could lead to an increase in exposure and therefore an increase in risk. For example, if a remedy includes the capping of contaminated soils, then the potential future exposures due to cap failure include direct contact with soils and the leaching of contaminants to ground water. The worst-case situation of complete containment system failure is unlikely to occur, however, because five-year reviews (see Section 3.4) are conducted at all sites where wastes are managed onsite above concentration levels that allow for unrestricted use and unlimited exposure.

2.2.2 EVALUATION OF SHORT-TERM HUMAN HEALTH RISKS FOR DETAILED ANALYSIS

Short-term health risks generally include any current baseline risks plus any new risks that would occur while implementing the remedy. As discussed previously, the evaluation of potential short-term risks involves the same general steps as in the baseline risk assessment. These steps,

however, generally will not be conducted in the same level of detail for the FS.

Other important points concerning level of effort should be emphasized here. For example, the Resource Conservation and Recovery Act (RCRA) has performance standards for many commonly used CERCLA remedial technologies (e.g., incineration). The risks associated with many of these technologies were analyzed in developing these standards, and the standards were set such that the risks associated with operation of the technology would be acceptable. Therefore, a detailed evaluation of the risks associated with RCRA-regulated technologies generally would not be necessary. On the other hand, depending on site-specific factors such as the toxicity of site contaminants and the proximity of populations, a more detailed evaluation of short-term risks may indeed be appropriate.

Detailed analyses may also be appropriate for less-characterized technologies (e.g., innovative technologies). In addition, alternatives with multiple short-term releases or substantial baseline risks may need a more detailed evaluation to determine whether cumulative risks are expected to be within acceptable levels.

Of special note is that the short-term risk evaluation for remedial alternatives during the detailed analysis includes an evaluation of the potential for short-term risks to two groups of individuals: (1) neighboring populations (which include onsite workers not associated with remediation) and (2) onsite workers associated with remediation.

Appendices A through D provide information that can be used when a more quantitative evaluation of short-term risks is needed to support the selection of a remedy. Chapter 8 of RAGS/HHEM Part A also provides guidance on characterizing short-term risk.

Evaluate Short-term Exposure. A qualitative exposure assessment for remedial alternatives during the detailed analysis generally involves — just as in the baseline risk assessment, but in a less quantitative manner — using the concept of reasonable maximum exposure (RME) to evaluate release sources, receiving media, fate and transport, exposure points, exposure routes, and receptors associated with a particular alternative.

An important difference between the baseline risk assessment and the risk evaluation of remedial alternatives involves exposure sources. For the baseline risk assessment, the source of exposure is untreated site contamination. For remedial alternatives, however, the potential sources of exposure are the releases that result from the implementation of remedial technologies. In addition, some remedial alternatives (e.g., incineration, biodegradation) may result in new chemicals that were not previously assessed for the site.

The first step of the exposure assessment involves identifying the types of releases associated with a particular waste management approach. During the detailed analysis, methods for mitigating potentially significant short-term releases should be examined, and releases that are expected to be most difficult to control should be highlighted.

Appendices A and D of this guidance each contain two matrices that should assist in characterizing the releases that may occur during remedy implementation. Exhibit A-1 provides a brief description of common remedial technology processes, and Exhibit A-2 summarizes potential releases to different media during the normal operation of various technologies. Exhibit D-1 provides a summary of releases associated with radiation remedial technologies, and Exhibit D-2 includes a qualitative estimate of the potential short-term risks posed by a radiation remedial technology.

After the releases and their receiving media have been identified, the next step of the exposure assessment is to determine whether major exposure pathways exist. Characterizing site-specific exposure pathways involves identifying:

- the general fate and transport of the contaminants that are released from the technology (e.g., downwind transport);

- the potential exposure points and receptors (e.g., nearby downwind residents); and

- potential exposure routes (e.g., inhalation).

Exhibit 2-1 illustrates an example of an exposure pathway for a remedial alternative. More detailed information concerning exposure pathways is available in Chapter 6 of RAGS/HHEM Part A.

The flow charts contained in Exhibit 6-6 of Part A are particularly useful in determining the populations potentially exposed by releases into a particular medium. Transfers of contaminants from one medium to other media also are addressed.

At this point, a quantitative exposure assessment — if needed — would involve (in addition to identifying release sources, exposure routes, and exposure points):

- quantifying releases;

- evaluating environmental fate and transport;

- determining exposure point concentrations; and

- calculating intakes.

All of these steps are discussed in Chapter 6 of RAGS/HHEM Part A.

Throughout the short-term exposure assessment, the assessor must continually ask whether the potential exposure warrants the level of quantitation being used. At times, the answer may not be known until the end of the exposure assessment. For example, if short-term exposure was estimated to be very similar to long-term exposure, it would not be necessary to expend resources to obtain the short-term toxicity information needed to quantitatively characterize risk.

A major difference between the exposure assessment conducted during the baseline risk assessment and the one conducted during the risk evaluation of remedial alternatives is the evaluation of the timing and duration of releases. Because a number of different activities will take place during implementation, it is likely that the quantities of hazardous substances released to the environment will vary over time. For example, as seen in Exhibit 2-2, one remedy can have several distinct phases, each with different exposure potentials. It may be important to determine the sequence of events and likely activities at each phase of the remediation, so that the exposure point can be evaluated for each phase. This will also ensure that appropriate short-term exposure durations are identified and that the potential for releases to occur simultaneously and thus result in cumulative risk is considered. As seen in

EXHIBIT 2-1

ILLUSTRATION OF AN EXPOSURE
PATHWAY FOR A REMEDIAL ACTION
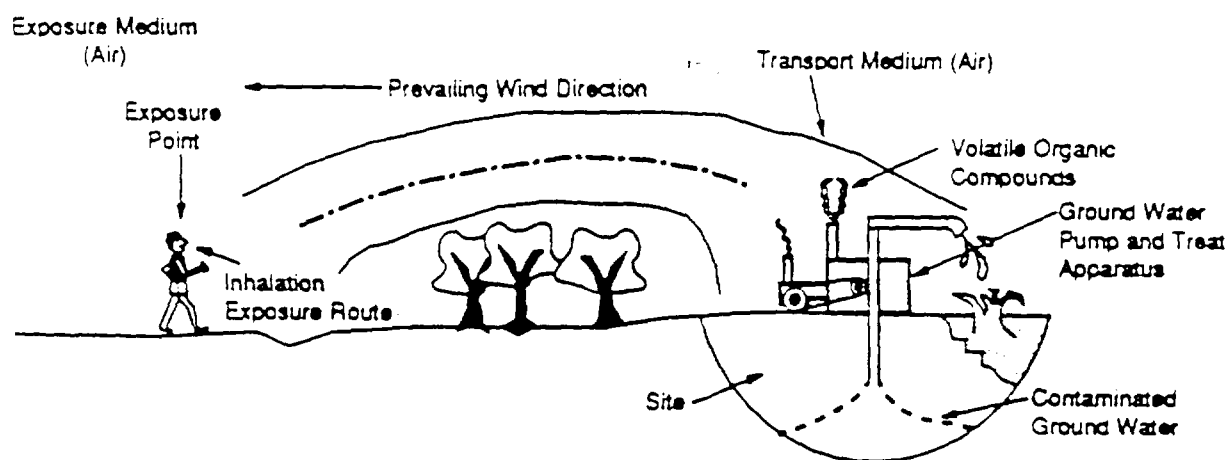
Exhibit 2-2, this issue is complicated by the possible presence of baseline exposures.

Appendix B provides references — organized based on several important categories of remedial technologies — that can be consulted to quantify the release of and therefore exposure to contaminants. The information in Appendix B includes a brief discussion of considerations in release modeling and monitoring, a list of key technology-related parameters generally needed as inputs for models (e.g., meteorological conditions, operation characteristics, soil/media characteristics), an annotated list of primary references, and a list of additional references.

Evaluate Short-term Toxicity. The releases that may occur during implementation of a remedial alternative, and hence the exposure-point concentrations, generally last for varying durations and correspond to less-than-lifetime exposures. Consequently, any toxicity values used to evaluate the risks from these shorter exposures must correspond to the duration of the release (or exposure). Three exposure durations, in addition to longer-term exposures, may be of concern at CERCLA sites undergoing remediation: single exposure events (minutes, hours, or single day), very short-term exposures (up to two weeks), and short-term exposures (two weeks to seven years). Note that the chronic toxicity values for noncarcinogenic effects used most frequently in the baseline risk assessment may not be appropriate without modification for exposures of less than seven years (otherwise they may be unnecessarily conservative).

EXHIBIT 2-2

ILLUSTRATION OF CUMULATIVE EXPOSURE FROM MULTIPLE RELEASES

Cumulative	—————
Residual	············
Technology 1	– · — ···
Technology 2	—· —· ····
Baseline (Uncontrolled)	– – – –

Exposure

Cumulative

Baseline (Uncontrolled)

Technology 2

Technology 1

Residual

Time
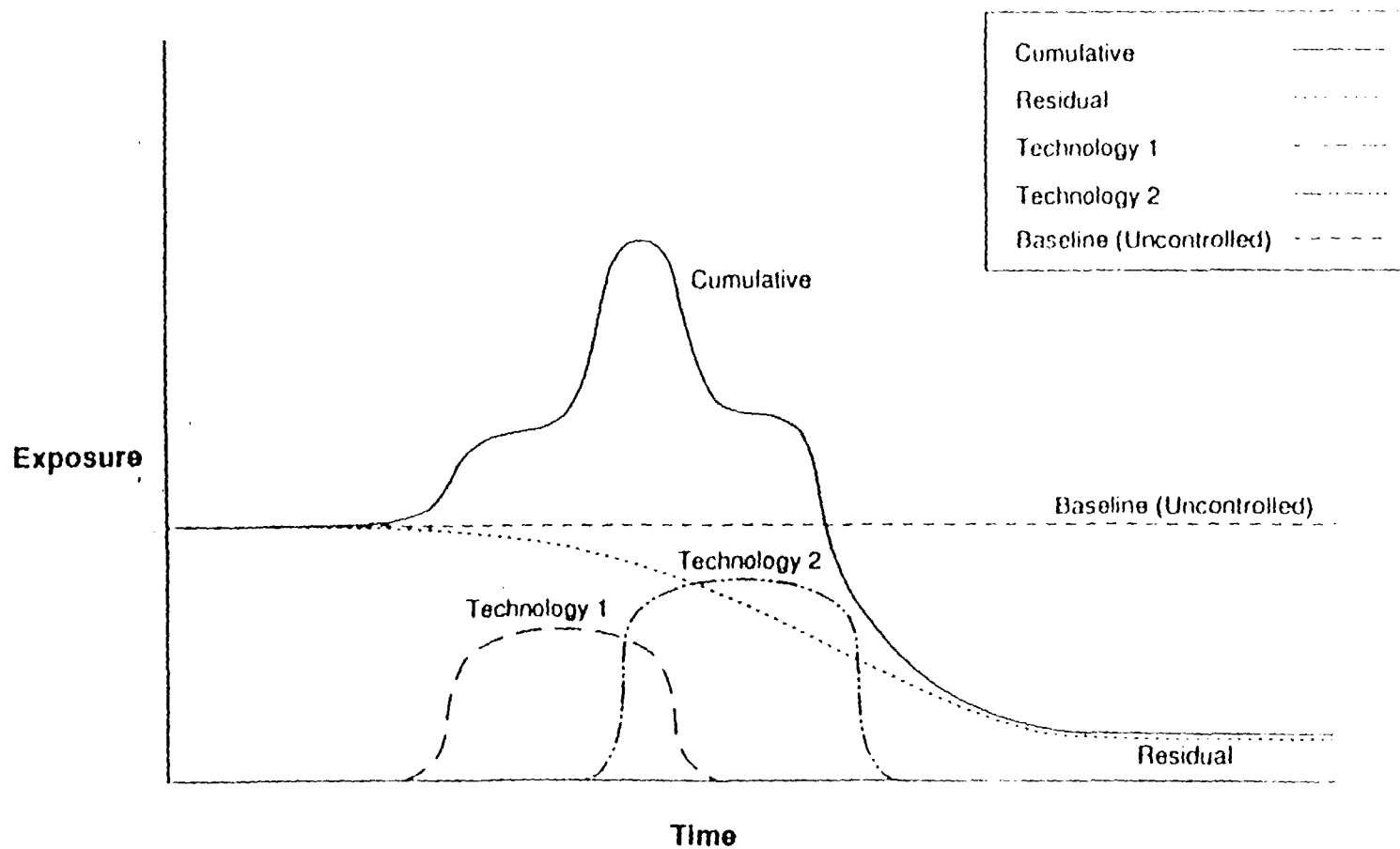
Note: The graph illustrates how nearby populations at some sites could be exposed to both residual risks and risks from remediation technologies. The cumulative exposure illustrated is the sum of residual exposure and exposures associated with releases from Technologies 1 and 2. This exhibit is for illustration purposes only and is not meant to imply that this level of quantitation is neccesary or even desired.

Appendix C contains information concerning the use of short-term toxicity values. RAGS/HHEM Part A provides additional information on assessment of contaminant toxicity. As discussed in Appendix C, the Superfund Health Risk Technical Support Center (TSC) should be consulted in all cases where short-term toxicity values are needed.

Characterize Short-term Risks to the Community. During risk characterization, exposure and toxicity information is brought together to provide a measure or indication of the magnitude and timing of short-term health risks (if any) from the remedial alternatives. As discussed previously, risk assessors may choose to characterize the short-term risks to the community (i.e., persons who live or work in the vicinity of the site) quantitatively for some sites and qualitatively for others. When short-term risks are not expected to be a problem for a site, a more qualitative evaluation generally is appropriate. In these cases, a qualitative evaluation of the magnitude, duration, and/or likelihood of the exposures and risks should be conducted, and assessors could describe short-term risks in a qualitative manner relative to the results of the baseline risk assessment.

A quantitative evaluation of short-term risks is most likely to be useful when the types, levels, and/or availability of hazardous substances are expected to change significantly as a result of remediation. If quantitative exposure estimates and toxicity data are available, then a more quantitative risk characterization may be conducted. The quantitative method that is used to characterize these risks depends in part on the toxicity values that have been identified. Some of these toxicity values (e.g., subchronic reference doses) must be combined with the results of the exposure assessment (i.e., intakes). The results of risk characterizations using this type of toxicity value will be of the same type as those generated in the baseline risk assessment: hazard quotients (or indices) or excess individual lifetime cancer risks. If the toxicity values incorporate exposure assumptions (e.g., as in one- and ten-day health advisories), then these values are compared with exposure concentrations to determine whether the risks are above acceptable levels. Appendix C provides additional information on short-term toxicity values.

Cumulative effects from multiple releases or multiple chemicals should also be considered, if possible. If the risk characterization is qualitative, then a discussion of the potential for cumulative risks from multiple chemicals and/or exposure pathways (e.g., due to simultaneous implementation of several remedial technologies) should be provided. If the results of the risk characterization are more quantitative (e.g., cancer risks and hazard quotients), then the information concerning duration and timing of releases can be used to calculate the cumulative risks or hazard indices for those releases that will occur at the same time and affect the same populations. If the results of the quantitative risk characterization are comparisons with short-term toxicity criteria, then the total exposure concentrations can be calculated for releases that occur at the same time and affect the same populations. These total exposure concentrations then can be compared to the short-term toxicity criteria. See Chapter 8 of RAGS/HHEM Part A for additional guidance on characterizing short-term human health risks.

Characterize Short-term Risks to Workers. Worker health and safety issues should also be considered during the development of the FS. The Worker Protection Standards for Hazardous Waste at 40 CFR 311 and 29 CFR 1910.120 establish requirements for worker protection at CERCLA sites, including requirements for planning (i.e., health and safety plans, and emergency response plans), training, and medical surveillance. Although the standards encompass areas that are not directly related to worker risk (e.g., illumination and sanitation), they also specify requirements in areas that are directly relevant to worker health risks. Specifically, once a remedy is selected, the Worker Protection Standards require that implementation of that remedy proceed with the following risk-related considerations:

- site characterization and analyses prior to commencing remedial activities, specifically risk identification (see 29 CFR 1910.120(c));

- proper use of engineering controls, work practices and personal protective equipment (PPE) for employee protection (see 29 CFR 1910.120(g)); and

- preparation of emergency response plans that specify how the site employees will be protected while responding to onsite

emergencies that may occur (see 29 CFR 1910.120(l)).

It is important to note, however, that factors not associated directly with hazards particular to a given site (e.g., risk of accidents during offsite motor vehicle transport) are not usually considered during the FS, but instead should be addressed prior to remediation in the site health and safety plan.

The exact nature of the assessment of worker safety issues for a remedial alternative will vary with each site. For many types of sites and remedial alternatives, the risks to workers will be well-characterized and will not require much additional site-specific analysis. These issues will be addressed in more detail in the site-specific health and safety plan. Thus, a qualitative assessment of worker risk is appropriate for most sites during the FS and can be based on three types of risk.

- Potential for exposure to hazardous substances during onsite remedial activities. The most significant factor determining the potential for exposure to hazardous substances is the nature of the onsite contamination. Because onsite remediation workers are equipped with the appropriate PPE and are required to use appropriate engineering controls, their risk generally should be minimal. Factors that affect the potential for exposure, however, include the likelihood of PPE failure. In general, more restrictive PPE is more likely to fail due to considerations such as worker mobility and visibility constraints, and potential for worker heat stress.

- Potential for injury due to physical hazards. Onsite remediation workers may be exposed to hazards other than exposure to hazardous substances. Hazards such as explosion, heat stress, and precarious work environments may also pose threats to workers.

- Potential for exposure during emergency response activities (assuming the need arises for onsite emergency response). Part of the design of a remedial alternative should consider the potential for worker exposure during emergency responses that may be required in the event of remedy failure. For some remedial alternatives, it is possible that emergency assistance would be handled in part by onsite workers, with offsite assistance (e.g., county HAZMAT teams) as required.

Alternatively, it is possible that an emergency response plan would require the evacuation of onsite remediation workers and use of offsite emergency responders.

2.3 CASE STUDIES

The following two case studies provide examples of the evaluations of long-term and short-term risks that are conducted during the detailed analysis. Both case studies present an evaluation of only one technology for one of several alternatives that are considered for the hypothetical site. An actual detailed analysis would include a similar evaluation for other technologies and alternatives as well. The two sites considered in the case studies are identical in all respects, except one: the XYZ Co. site considered in Case Study #1 is distant from residential or worker populations, while the ABC Co. site considered in Case Study #2 is adjacent to a residential neighborhood. A more quantitative analysis was conducted in Case Study #2 because of concern for potential short-term exposures to the neighboring community.

The sites presented in these case studies are abandoned industrial facilities that are contaminated with various volatile organic compounds (VOCs) and heavy metals. VOCs contaminate both the soil and ground water at the sites, while metals are found in the soil only. A number of leaking drums were stored above ground at the sites and were removed prior to the RI. There are also two lagoons filled with hazardous sludges. City ground-water wells are located approximately 1/4 mile from the sites. VOCs have been detected in the wells at levels high enough to force the city to use an alternate water source.

CASE STUDY #1:
QUALITATIVE EVALUATION DURING DETAILED ANALYSIS

[Note: This case study presents an evaluation of only one technology for only one of several remedial alternatives; an actual detailed analysis would address other technologies and alternatives as well. All data in this case study are for illustration purposes only.]

Remedial Alternatives

Based on the results of the development and screening of alternatives, the site engineers have identified five alternatives (A through E) to be evaluated for use as remedies at the XYZ Co. site. One of the technologies included in Alternative C is ground-water pumping and air stripping for the VOCs in ground water.

Evaluation of Long-term Risks

Meeting PRGs for all contaminants in ground water is uncertain at this point due to the complex nature of the contaminated aquifer. If after remedy implementation it is determined that Alternative C does not meet PRGs for all contaminants in ground water, then the residual risk remaining after implementation will be examined to determine whether other measures need to be taken to assure protectiveness. There are no residual risks for media other than ground water for the pump-and-treat/air stripping component of Alternative C.

Evaluation of Short-term Risks

The time-frame for air stripping of VOCs from ground water at the XYZ Co. site — and therefore the time frame considered for evaluating short-term risks — is at least 20 years, and possibly as many as 50, depending on factors such as the specific aquifer characteristics.

Releases and Receiving Media. The most likely release of concern from an air stripper is the release of air contaminated with VOCs. The type of air stripper being considered for the XYZ Co. site generally achieves 99 percent or better removal of VOCs from water. The vapor phase VOCs contained in the air stripper off-gases then can be removed if necessary using air pollution control devices such as granular activated carbon columns or an afterburner, which generally achieve 90 to 99 percent destruction or removal of contaminants from the vapor phase. However, there will still be some small release of contaminants that may need to be examined further during the design stage of this remedy (if selected). Also, air pollution control devices will produce residues that in turn may need to be treated. Other releases associated with air stripping include treated water containing residual organic contaminants that will be released to surface water, and, possibly, fugitive air emissions due to leaky valves and fittings.

Fate and Transport, Exposure Points, and Exposure Routes. The release of VOCs into the air during air stripping at the XYZ Co. site could result in inhalation of volatiles transported through the air. However, the nearest target population is over one mile from the site. Long-term average concentrations may be a concern, as well as shorter-term or peak concentrations that may occur under certain conditions (e.g., temperature inversions).

Short-term Risks. The time period of exposure to air stripper off-gases (20 to 50 years) is a significant portion of a human lifetime. However, because the concentrations of VOCs in ground water are not unusually high, the releases associated with the air stripper are well-characterized, and there is no nearby target population, quantitation of these risks is not needed to select a preferred alternative.

CASE STUDY #2:
QUANTITATIVE EVALUATION DURING DETAILED ANALYSIS

[Note: This case study presents an evaluation of only one technology for only one of several remedial alternatives: an actual detailed analysis would address other technologies and alternatives as well. All data in this case study are for illustration purposes only.]

Remedial Alternatives

Based on the results of the development and screening of alternatives, the site engineers have identified five alternatives (A through E) to be evaluated for use as remedies at the ABC Co. site. One of the technologies included in Alternative C is ground-water pumping and air stripping for the VOCs in ground water. [For this case study, only benzene from the pump-and-treat component of the remedial alternative will be analyzed in detail. In an actual analysis, each contaminant of concern and each component of the remedy may need to be analyzed in a similar fashion.]

Evaluation of Long-term Risks

The RI has shown that the organic contaminants in the ground water are adsorbed to the aquifer material and are also dissolved in the ground water. The remediation goal for benzene will be readily met in the treated water, which will subsequently be discharged into the nearby surface water. Remediation of the water remaining in the aquifer, however, is much less certain. The residual concentration of benzene in this remaining water will depend on several factors, including the adsorptive characteristics of benzene with the aquifer material, the specific pumping regimen, and the length of time that this technology is implemented. If, at a later stage (e.g., during the five-year review), it is determined that the contaminants are not being extracted at the desired levels, the pumping regimen may need to be modified (or some other approach may be needed). At a minimum, the pumping of ground water is expected to be an effective barrier against further contaminant migration. Due to the uncertainty regarding the residual concentration of contaminants that may remain in ground water, the permanence of the pump-and-treat technology, in terms of future risks, is unknown at this time.

Evaluation of Short-term Risks

Short-term impacts due to air emissions from air stripping are expected to be the most significant risks from the pump-and-treat component of the remedy at ABC Co. site. [This case study does not consider fugitive emissions from sources "upstream" of the air stripper (e.g., separators, holding tanks, treatment tanks), although these sources may have been evaluated in an actual risk assessment.] In order to assess these risks during the detailed analysis stage, exposure concentrations from the ABC Co. site will be estimated by combining emissions modeling with dispersion modeling. Before proceeding with this analysis, the following steps were taken.

- An appropriate atmospheric fate and transport model, derived from the SCREEN model developed by EPA's Office of Air Quality and Planning Standards was chosen. (A more complete listing and comparison of atmospheric fate models is given in Table 3-2 of the *Superfund Exposure Assessment Manual* [EPA 1988e].)

- Required inputs for the atmospheric fate and transport model were obtained. These inputs included the emission rate of contaminants from the air stripper into the atmosphere (based on contaminant concentrations in ground water, system flow rate efficiency of the air stripping process, and efficiency of the air pollution control device); atmospheric dispersion factors for contaminants; and meteorological data (wind speed, prevalent direction, stability, mixing height, and temperature). More detailed parameters, such as surface roughness height and specific topographic features, were not required for the model that was chosen.

(Continued)

- The population that will be affected by short-term releases was identified. This information was obtained from the baseline risk assessment, and was based on the population distribution and density of the surrounding community, and meteorological data such as the prevailing wind direction.

- The toxicity characteristics of the contaminants were obtained from the baseline risk assessment.

Exposure Assessment. Releases are expected to occur during both the construction and the implementation stages of the pump-and-treat technology. The time frame for each of these stages varies and, therefore, the release and exposure potential also will vary. The most probable release of concern from implementation of the air stripper [the focus of this case study] has been identified as the release of air contaminated with volatile organic chemicals (VOCs) from the stripping tower to the atmosphere. Benzene is one of the volatile contaminants in the ground water being treated, and is expected to be present as a residual in the stripper off-gases. The following equation (EPA, Emission Factors for Superfund Remediation Technologies, Draft, Office of Air Quality Planning and Standards, 1990) was used to calculate the benzene emission rate into the air stripper off-gases:

$$ER \text{ (g/s)} = C \times Q_{in} \times (SE/100) \times K$$

where
ER = emission rate of benzene (g/s)
C = concentration of benzene in water = 2.5 mg/L
Q_{in} = influent water flow rate = 1700 L/min
SE = stripping efficiency of tower for benzene = 99.99%
K = constant to convert units = 1.67×10^{-5} (g-min/mg-s)

An SE of 99.99 percent is used in these calculations to determine the reasonable maximum emission rate of benzene into the air. Actual SEs would be between 90 and 99.99 percent, depending on several operating parameters. Solving this equation, ER = 0.071 g/s.

Because this system will use an air pollution control device (APCD) such as granular activated carbon (GAC) columns to remove contaminants from gases released to the atmosphere, ER is the rate of release of benzene from the ground water into the stripper off-gases rather than the rate of release of benzene directly to the atmosphere. The release rate of benzene to the atmosphere, therefore, can be calculated using the following equation:

$$q = ER \times (1 - DRE/100)$$

where
q = mass release rate to atmosphere (g/s)
ER = emission rate from air stripper to APCD = 0.071 g/s
DRE = destruction/removal efficiency of APCD = 95%

A DRE of 95 percent is used to obtain a reasonable maximum release rate to the atmosphere. Applications of similar APCDs achieve 95 to 98 percent destruction and removal efficiency for benzene in air. Solving for the atmospheric release rate of benzene, q = 0.0035 g/s.

Using fate and transport modeling [analysis not shown], the atmospheric release rate of benzene is converted to an exposure point concentration at a residence 250 m downwind of the site. The short-term air concentration (24-hour average) of benzene is estimated to be 6×10^{-4} mg/m³. The average annual longer-term concentration of benzene in air at the site boundary, as determined by the same model, is estimated to be 3.4×10^{-4} mg/m³.

(Continued)

CASE STUDY #2:
QUANTITATIVE EVALUATION DURING DETAILED ANALYSIS
(Continued)

The only potential exposure pathway identified for releases from the air stripper is the air (inhalation) pathway. Because the toxicity criterion used to characterize short-term risk is a threshold concentration (see Toxicity Assessment below), a short-term intake does not need to be calculated. The longer-term intake is needed to evaluate the cancer risk associated with inhalation of benzene. This intake is calculated by first obtaining the long-term site-specific exposure duration of 30 years from the baseline risk assessment. (An exposure duration of 30 years is used because, while the time for implementation of the pump and air stripping technology may be up to 50 years, an individual is not expected to stay in the community for more than 30 years. If the maximum time for implementation were less than the exposure duration identified in the baseline risk assessment, then exposure would be computed using the maximum implementation time as the exposure duration.) Using other exposure values obtained from the baseline risk assessment (e.g., inhalation rate of 20 m³/day), the longer-term (lifetime average) intake of benzene due to the air stripper is approximately 7.3 x 10⁻⁵ mg/kg-day.

These concentrations and intakes are based on conservative steady-state assumptions regarding atmospheric conditions. Therefore, there is uncertainty surrounding the atmospheric data (which are inputs to the model) that could lead to higher (but probably lower) concentrations. For example, variations in wind speed and direction will result in different contaminant concentrations for both maximum short-term and long-term exposure point concentrations. Some amount of published research data is available (mainly from water treatment plant studies) on the reliability of the APCDs used in air stripping. This information, combined with data from previous program experience, indicates that the uncertainty associated with the effectiveness of the APCDs is low.

Toxicity Assessment. To assess risk from exposure to the short-term benzene concentration (24-hour average), a toxicity criterion corresponding to a similar exposure duration is used. One such criterion, identified through consultation with the TSC, is EPA's acute inhalation criteria (AIC). The AIC provides a threshold level above which acute inhalation exposure to benzene could result in toxicity to the most sensitive target organ (bone marrow and the immune system). The AIC for benzene is 190 ug/m³. [In this case study, the AIC for benzene was assumed to be readily available. In an actual risk evaluation, this may not always be the case. When toxicity information is not readily available — especially when, as in this case study, the longer-term exposure point concentration is not significantly different from the shorter-term point concentration (and the longer-term has toxicity information) — then either delaying the assessment or expending resources to obtain the shorter-term toxicity information is not recommended.]

To assess risk from exposure to the longer-term benzene concentration (annual average) for the 30-year exposure duration, the inhalation cancer slope factor for benzene of 0.029 (mg/kg-day)⁻¹ is identified from the baseline risk assessment.

Risk Characterization. Short-term risk to the community from benzene is determined by comparing the short-term concentration of 6 x 10⁻⁴ mg/m³ (i.e., 0.6 ug/m³), with the AIC of 190 ug/m³, to result in a ratio of 0.003. Because this ratio is less than 1, short-term risk to the community solely from benzene is considered to be unlikely.

Using the longer-term intake of 7.3 x 10⁻⁵ mg/kg/day, and the slope factor of 0.029 (mg/kg/day)⁻¹, the upper-bound excess individual lifetime cancer risk to the community from long-term exposure to benzene in the atmospheric releases from the air stripper is approximately 2 x 10⁻⁶, within EPA's acceptable risk range.

[Uncertainties associated with the site-specific exposure information and the toxicity information, discussed in more detail in the baseline risk assessment, also are important to consider at this stage of the analysis.]

CHAPTER 3

RISK EVALUATION AFTER
THE FEASIBILITY STUDY

After the FS is completed, a remedy is proposed, and, if selected, is documented in the ROD. Following this, the remedy is designed and implemented, and then deletion/five-year reviews of the site take place. This chapter discusses the role of risk information during these activities. Note, however, that not all of these risk evaluations nor a significant level of quantitation may be needed for every site. The guiding principle is that risk evaluations after the FS should be conducted as necessary to ensure that the remedy is protective.

3.1 RISK EVALUATION FOR THE PROPOSED PLAN

The purpose of a risk evaluation during the proposed plan stage is to refine previous analyses conducted during the FS, as needed. If new information becomes available during the public comment period for the proposed plan, additional analysis of the alternatives may need to be conducted at this time. If additional analysis is conducted, it should be conducted for all the alternatives, as appropriate, and not just for the preferred alternative.

3.2 DOCUMENTATION OF RISKS IN THE ROD

Several risk-related analyses should be documented in the ROD. The comparative analysis section should include a discussion of risk as it pertains to the three risk-related criteria: long-term effectiveness, short-term effectiveness, and overall protection of human health and the environment. The discussion of overall protection of human health and the environment should include a discussion of how the remedy will eliminate, reduce, or control the risks identified in the baseline risk assessment and whether exposure will be reduced to acceptable levels. The discussion of long-term effectiveness (and

permanence) should address, where appropriate, the residual risk from untreated waste remaining at the site. The part of the decision summary that focuses on the selected remedy should present:

- the chemical-specific remediation levels to be attained at the conclusion of the response action;

- the corresponding chemical-specific risk levels;

- the points (or areas) of compliance for the media being addressed; and

- the lead agency's basis for the remediation levels (e.g., risk calculation, ARARs).

In addition, the ROD should indicate whether the site will require five-year reviews (see Section 3.4). In some cases, additional risk information (e.g., anticipated post-remedy cumulative risk for an environmental medium or for a site) may need to be included in the ROD.

Interim Final Guidance on Preparing Superfund Decision Documents (EPA 1989f), *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions* (EPA 1991d), and RAGS/HHEM Part B provide additional information on documenting risks in the ROD.

3.3 RISK EVALUATION DURING REMEDIAL DESIGN/ REMEDIAL ACTION

The activities during remedy design and implementation that may involve consideration of risk include refining risk evaluations during remedial design, monitoring short-term risks, evaluating attainment of remedial levels in the ROD, and evaluating residual risk.

3.3.1 RISK EVALUATION DURING REMEDIAL DESIGN

The process of evaluating long-term and short-term risks, which began during the FS and may have continued during development of the proposed plan, also may continue during design of the selected remedy for some sites. The purpose for risk evaluations during the remedial design is to ensure that the selected remedy will be protective. These evaluations can be conducted by: (1) refining previous analyses, as needed, and/or (2) identifying the need for engineering controls or other measures to mitigate risks. Methods for evaluating long-term and short-term risks are discussed in more detail in Chapter 2.

3.3.2 MONITORING SHORT-TERM HEALTH RISKS DURING IMPLEMENTATION

If the potential for short-term health effects due to releases during remedy implementation needs to be assessed (e.g., due to high uncertainty concerning predicted risks to communities or remediation workers), a sampling and analysis strategy to accurately determine exposure concentrations should be developed. This strategy may need to consider the following elements:

• location of sampling;

• sample collection and handling procedures;

• chemicals to be monitored and methods used; and

• statistical considerations regarding the analysis of results.

The monitored exposure concentrations should be compared to short-term health-based benchmarks (see Appendix C) to help in determining whether the release presents a threat to human health.

3.3.3 ASSESSING ATTAINMENT OF SELECTED REMEDIATION LEVELS DURING IMPLEMENTATION

The RPM, risk assessor, and others should be involved in developing a sampling and analysis plan to measure whether the selected remedy has attained the remediation levels in the ROD. As in the baseline risk assessment, this sampling and analysis should provide data that can be used to develop RME estimates. This plan is site-specific and may need to consider the same elements presented in Section 3.3.2, plus the relevant remediation levels for the chemicals of concern.

The plan for measuring attainment should ensure that sufficient data to evaluate protectiveness of human health will be available. For example, at a minimum, those chemicals that contribute to major portions of the site risk should be selected for measuring attainment. The two-volume set *Statistical Methods for Evaluating the Attainment of Cleanup Standards* (EPA 1988d) outlines a number of statistical methods that can be used to measure attainment. EPA is developing additional guidance on this topic.

3.3.4 EVALUATION OF RESIDUAL RISK

This step — which may be conducted at completion of the remedy and perhaps during a five-year review (see next section) — may be needed to ensure that the remedy is protective. This step may be different from the assessment of attainment of remediation levels selected in the ROD because it may more closely consider the expected land use and cumulative effects (e.g., due to multiple chemicals or exposure pathways). Residual risk estimates can be conducted at any time after the remedy has commenced until the end of the remedy. Typically, a final evaluation of the cumulative site risk may be done following completion of the final operable unit to ensure that residual risks from multiple contaminants, pathways, and operable units that affect the same individuals are at protective levels.

In general, the same equations, exposure parameters, and toxicity values that were used to determine the baseline risk for a site can be used to assess the final clean-up (risk) level that remedy has achieved. The concentrations that are used to calculate these risks, however, are the final measured concentrations of the contaminants that remain at the site, not the remediation levels the ROD. The following are other potential differences between the baseline risk assessment and evaluation of residual risks.

• Significant levels of "new" chemicals (e.g., that were not identified during the baseline risk assessment but that may have resulted from the remedy or were not discovered until after remedy implementation) should be considered in evaluating residual risk.

- Changes in land use since the time of the baseline risk assessment may require changes in exposure parameters (e.g., contact rates, exposure frequency and duration).

- Toxicity values may have been updated since the baseline risk assessment. The most recent toxicity values in IRIS and HEAST should be used in calculating residual risk.

For some sites where engineering or institutional controls rather than treatment-based remedies are employed, the concentrations of chemicals in a contaminated medium may remain the same as the baseline concentrations. The risk will have been reduced or eliminated, however, by mitigation or elimination of the exposure pathway (e.g., by mitigating direct contact with soil by using a cap or institutional controls, or eliminating ingestion of contaminated drinking water by providing an alternate water supply). These risk reductions and associated exposure assumptions should be clearly presented.

3.4   RISK EVALUATION DURING FIVE-YEAR REVIEWS

Section 121(c) of CERCLA provides for reviews of remedies that result in hazardous substances remaining at the site no less often than every five years after the initiation of the remedies. The purpose of the reviews is to assure that human health and the environment are being protected by the remedial alternative that was implemented.

The remainder of this section briefly describes the purpose of five-year reviews, the sites for which five-year reviews are conducted, and the risk-related activities that may be conducted during five-year reviews. More detailed guidance regarding five-year reviews is available in *Structure and Components of Five-year Reviews* (EPA 1991e).

3.4.1   PURPOSE OF FIVE-YEAR REVIEWS

A five-year review is intended to ensure that a remedy remains protective of human health and the environment. The more specific goals of a five-year review are:

- to confirm that the remedy (including any engineering or institutional controls) remains operational and functional; and

- to evaluate whether clean-up standards (based on risk or ARARs) are still protective.

The first goal may be accomplished primarily through a review of the operation and maintenance records for a site and through a site visit and limited analysis. The second goal includes an analysis of requirements that have been promulgated by the federal or state governments since ROD signature to determine whether they are ARARs and whether they call into question the protectiveness of a remedy.

In addition to considering ARARs for substances designated as contaminants of concern in the ROD, the reviews may include changes in ARARs for substances not addressed under contaminants of concern. Where remediation levels in the ROD were based on risk calculations (rather than ARARs), then new information — such as revised toxicity values or exposure parameters — that could influence the protectiveness of the remedy should be considered. Based on this analysis, the reviewer can determine whether the original remediation levels set out in the ROD are still protective.

3.4.2   SITES THAT RECEIVE FIVE-YEAR REVIEWS

Two types of five-year reviews are conducted: statutory and policy. Statutory reviews are conducted for remedies selected after the enactment of SARA where, after the remedy is complete, hazardous substances are present above levels that allow for unlimited use and unrestricted exposure. These sites generally include: (1) sites with remedies requiring access or land-use restrictions or controls (i.e., remedies that achieve protectiveness through the use of engineering or institutional controls); and (2) sites with remedies that achieve protectiveness for the current use, but include restrictions on activities due to limits on exposure (i.e., sites cleaned up to levels that would be protective for a nonresidential land use, but would not be protective for residential or other land use). Policy reviews are conducted for: (1) sites with long-term remedial actions (LTRAs) or other remedies that require five years or longer to achieve levels that would allow for unlimited use and unrestricted exposure and (2) remedies selected before the enactment of SARA where hazardous substances are present above levels that allow for unlimited use and unrestricted exposure.

Statutory reviews may be discontinued only if levels of hazardous substances fall permanently to a point that would allow unlimited use and unrestricted exposure. Policy reviews for LTRAs should be discontinued when the remediation goals specified in the ROD are achieved. assuming these levels allow for unlimited use and unrestricted exposure. Achievement of these levels must be verified by an appropriate period of monitoring.

3.4.3 RISK-RELATED ACTIVITIES DURING FIVE-YEAR REVIEWS

Three levels of effort have been defined for five-year reviews. The following are risk-related activities conducted for the three levels.

- At Level I, the reviewer will consider the risk assessment information contained in the ROD and ROD summary.

- At Level II, the reviewer will conduct a recalculation of the original baseline risk assessment using information obtained during the review (e.g., new toxicity data). If appropriate, additional data may be collected. Ongoing monitoring may provide such data.

- At Level III, the reviewer will reevaluate the risk assessment, and, if appropriate, conduct a new risk assessment. Such an assessment may be appropriate in order to address a new site condition, such as a new exposure pathway. New data may be collected as necessary for the risk assessment. If possible, however, existing data should be used.

The appropriate level of review depends on site-specific conditions and the confidence level for the selected remedy. The proposed level of the first review is to be included in the ROD. A Level I review should be appropriate in all but a few cases where site-specific circumstances suggest another level either at the outset of the review or because findings of the review suggest the need for further analysis. A Level III review would not be proposed in the ROD, but would be initiated in response to specific concerns regarding the performance of the remedy or the risks at the site. The level of effort, particularly for subsequent reviews, also depends on the initial findings of the review. *Structure and Components of Five-year Reviews* (EPA 1991e) provides additional information concerning the appropriate level for reviews and the activities that are conducted at each level.

REFERENCES

U.S. Environmental Protection Agency (EPA). 1988a. *Community Relations in Superfund: A Handbook. Interim Version.* Office of Emergency and Remedial Response. EPA/540/6-88/002 (OSWER Directive 9230.0-3B).

EPA. 1988b. *Guidance on Remedial Actions for Contaminated Ground Water at Superfund Sites.* Interim Final. Office of Emergency and Remedial Response. EPA/540/G-88/003 (OSWER Directive 9283.1-2).

EPA. 1988c. *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA.* Interim Final. Office of Emergency and Remedial Response. EPA/540/G-89/004 (OSWER Directive 9355.3-01).

EPA. 1988d. *Statistical Methods for Evaluating the Attainment of Superfund Cleanup Standards Volume I: Soils and Soil Media.* Office of Policy, Planning, and Evaluation. EPA 230/02-89-042.

EPA. 1988e. *Superfund Exposure Assessment Manual.* Office of Emergency and Remedial Response. EPA/540/1-88/001 (OSWER Directive 9285.5-1).

EPA. 1988f. *Seven Cardinal Rules of Risk Communication.* Office of Public Liason. OPA-87-020.

EPA. 1989a. *Considerations in Ground Water Remediation at Superfund Sites.* Office of Emergency and Remedial Response. OSWER Directive 9355.4-03.

EPA. 1989b. *Ecological Assessment of Hazardous Waste Sites: A Field and Laboratory Reference.* Environmental Research Laboratory. EPA/600/3-89/013.

EPA. 1989c. *Estimation of Air Emissions from Clean-up Activities at Superfund Sites.* Office of Air Quality Planning and Standards. EPA-450/1-89-003.

EPA. 1989d. *Exposure Factors Handbook.* Office of Health and Environmental Assessment. EPA/600/8-89/043.

EPA. 1989e. *Interim Guidance for Soil Ingestion Rates.* Office of Solid Waste and Emergency Response. OSWER Directive 9850.4.

EPA. 1989f. *Interim Final Guidance on Preparing Superfund Decision Documents.* Office of Emergency and Remedial Response. OSWER Directive 9335.3-02.

EPA. 1989g. *Risk Assessment Guidance for Superfund: Volume I — Human Health Evaluation Manual (Part A, Baseline Risk Assessment).* Interim Final. Office of Emergency and Remedial Response. EPA/540/1-89/002.

EPA. 1989h. *Risk Assessment Guidance for Superfund: Volume II — Environmental Evaluation Manual.* Interim Final. Office of Emergency and Remedial Response. EPA/540/1-89/001A (OSWER Directive 9285.7-01).

EPA. 1990a. *Guidance for Data Useability in Risk Assessment.* Office of Solid Waste and Emergency Response. EPA/540/G-90/008 (OSWER Directive 9285.7-05).

EPA. 1990b. *Guidance on Remedial Actions for Superfund Sites with PCB Contamination.* Office of Emergency and Remedial Response. EPA/540/G-90/007 (OSWER Directive 9355.4-01).

EPA. 1991a. *Conducting Remedial Investigations/Feasibility Studies for CERCLA Municipal Landfill Sites.* Office of Emergency and Remedial Response. EPA/540-P-91/001 (OSWER Directive 9355.3-11).

EPA. 1991b. *Risk Assessment Guidance for Superfund, Volume 1. Human Health Evaluation Manual. Supplemental Guidance: "Standard Default Exposure Factors".* Office of Emergency and Remedial Response. OSWER Directive 9285.6-03.

EPA. 1991c. *Risk Assessment Guidance for Superfund: Volume 1 — Human Health Evaluation Manual (Part B. Development of Risk-based Preliminary Remediation Goals).* Interim. Office of Emergency and Remedial Response. OSWER Directive 9285.7-01B.

EPA. 1991d. *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions.* Office of Solid Waste and Emergency Response. OSWER Directive 9355.0-30.

EPA. 1991e. *Structure and Components of Five-year Reviews.* Office of Emergency and Remedial Response. OSWER Directive 9355.7-02.

EPA. 1991f. *Guidance on Oversight of Potentially Responsible Party Remedial Investigations and Feasibility Studies.* Office of Solid Waste and Emergency Response. EPA/540/G-91/010a (OSWER Directive 9835.1(c)).

APPENDIX A

SELECTED REMEDIATION TECHNOLOGIES AND ASSOCIATED POTENTIAL RELEASES

This appendix contains two exhibits designed to assist during the FS in identifying some of the potential releases that are associated with commonly used remediation technologies. Exhibit A-1 briefly describes each of the process options of each technology in Exhibit A-2. Exhibit A-2 summarizes several potential releases to air or water of common remedial technologies. Process variations for which potential releases are similar are combined under the technology category. Potential releases to surface water or ground water are included in the "water" column. "Other" releases include treatment residuals that need further treatment or proper disposal. In most cases, this column refers to sludge or solid residues that may also be hazardous.

Risk Reduction Engineering Laboratory (RREL; Cincinnati, Ohio) plans and conducts engineering, research, and development related to treatment of solid and hazardous wastes. RREL personnel provide site-specific technical services involving specific treatment technologies and CERCLA response processes including:

*   analysis of treatment alternatives,
*   treatability studies,
*   remedial design review,
*   construction QA/QC methods, and
*   contaminant source control and geotechnical test methods.

Regional EPA CERCLA staff should direct questions regarding evaluations of remediation technologies, previous experience with remediation technologies, and releases associated with remediation technologies to the Engineering and Treatment Technical Support Center, RREL at FTS 684-7406 or 513-569-7406.

EXHIBIT A-1

REMEDIATION TECHNOLOGY DESCRIPTIONS

Technologies	Description of Process
SOIL AND SLUDGE	
Soil Handling	
Soil Excavation, Transport, Dumping, and Grading	These processes use mechanized equipment to move contaminated soil. For some treatment techniques, soil must be removed from a contaminated site and be transported for treatment. Soil is then returned and replaced at either the original excavation or another disposal site. Grading is a technique which can reduce infiltration into contaminated soils and can also control runoff.
Thermal Destruction	These are destruction processes which control temperature and oxygen availability, and convert hazardous materials to carbon dioxide, water, and other products of combustion.
Circulating Bed Incineration	Wastes and auxiliary fuel are introduced into the combustion chamber. Air is forced up through the chamber from the bottom to promote mixing and complete combustion. Particulate and gaseous products of combustion exit from the top of the combustion chamber for treatment and disposal.
Rotary Kiln Incineration	The combustion chamber is a rotating, inclined cylinder which mixes combusting materials as it rotates. Wastes are fed into the chamber at the high end, along with air and auxiliary fuel. Exhaust gases are treated and released, and ash residue is collected on the low end of the kiln.
Fluidized Bed Incineration	A bed of inert particles (e.g., sand) lies at the bottom of the cylindrical combustion chamber. Air is forced up through the bed and the particles are fluidized (i.e., the particles "float" in the airstream). Wastes and fuel are injected at the top of the chamber, into the fluidized mass, where the mixture combusts. The turbulent atmosphere in the chamber provides good mixing of wastes to ensure complete combustion and efficient heat transfer.
Infrared Incineration	...erials are fed into the furnace on a conveyor belt, and pass through on a wire mesh belt. Heating elements provide infrared energy, oxidizing the materials. Waste gases are passed through a secondary combustion chamber; ash exits on the conveyor.
Pyrolysis	Organics are slowly volatilized at lower temperatures than incineration processes. Waste is fed into the primary combustion chamber and thermally treated without sufficient oxygen to completely combust. Volatilized organics pass to a secondary chamber and are incinerated. Solid residues from the primary chamber receive other treatment.

REMEDIATION TECHNOLOGY DESCRIPTIONS

Technologies	Description of Process
Wet Air Oxidation	The high temperature and high pressure properties of water are utilized in destroying wastes. Contaminated solutions are treated at high temperatures (>600° C) and pressures (3400 psi to 3700 psi). Contaminants are oxidized to simple organic compounds as large amounts of oxygen are dissolved in solution.
Aqueous Thermal Decomposition	Aqueous thermal decomposition works on the same principles as wet air oxidation, without the addition of excess oxygen.
Dechlorination	
Glycolate Dechlorination	Using a specific solvent, chlorine atom(s) are removed from chlorinated hazardous materials, and toxic compounds are converted to less toxic, more water-soluble compounds. Reaction products are more easily removed from soil and more easily treated.
Biological Treatment	
Composting	Contaminated material is mixed with bulking agents (e.g., sawdust, wood chips) and placed in reactor vessels or piles. Aeration, temperature, and nutrient levels are controlled to encourage microbial growth. Microorganisms then metabolize contaminants, breaking them down into less-harmful materials.
In-situ Biodegradation	Microorganisms are encouraged to decompose contaminants in soil without excavating the soil and placing it in a controlled reactor. Nutrients, oxygen, and other necessary materials can be injected into the contaminated area.
Slurry-phase Biodegradation	The wastes are mixed with water to achieve an aqueous mixture. The mixture is then treated in a bioreactor, where it is mixed continuously to contact microorganisms and contaminants. The bioreactor serves as a controlled environment for contaminant degradation.
Solid-phase Biodegradation	Soils are excavated and treated above ground so that treatment conditions can be closely monitored and adjusted to conditions that are ideal for biodegradation. Materials are treated in a prepared area which can include volatile emissions collection and leachate collection.

EXHIBIT A-1 (Continued)

REMEDIATION TECHNOLOGY DESCRIPTIONS

Technologies	Description of Process
Vacuum/Vapor Extraction, Thermal Desorption	
Low Temperature Thermal Stripping	Air, pressure, heat, and/or mechanical agitation provides a driving force for volatilizing and removing contaminants from soil into an airstream for further treatment. Separating contaminants from soil simplifies the final treatment of contaminants.
In-situ Vacuum/Steam Extraction	VOCs are removed from soil by applying a vacuum to wells that are placed in the contaminated soil. VOC vapors are collected and treated above ground. Some systems also inject hot air or steam into contaminated zones, raising temperatures and volatilizing organic chemicals.
Chemical Extraction & Soil Washing	
In-situ Chemical Treatment	Treatment chemicals are applied directly to contaminated soil. A variety of compounds can be applied, including neutralizing agents, oxidants, solidification/stabilization agents, and nutrients for biological treatment.
Chemical Extraction & Soil Washing	Contaminants are washed from the excavated soil into a chemical solvent. The liquid is treated to remove and destroy contaminants, and the solvent is reused.
In-situ Soil Flushing	Inorganic or organic contaminants are extracted from soil by washing the soil with solvents. Solvents are recovered, contaminants are extracted, and the solvents are recirculated through the soils.
Immobilization	
Capping	Contaminated soil is covered with low-permeability layers of synthetic textiles or clay. The cap is designed to limit infiltration of precipitation and thus prevent migration of contaminants away from the site and into ground water.
Solidification/Stabilization	Wastes are converted to chemically stable forms or are bound in a stable matrix. Chemical reactions are utilized to transform hazardous materials into new, non-hazardous materials. The goal is to prevent migration of contaminants.
In-situ Vitrification	Electrodes are placed vertically into the contaminated soil region, and an electrical current is applied. The soil is melted by the resulting high temperatures. When the melt cools and solidifies, the resulting material is stable and glass-like, with contaminants bound in the solid

EXHIBIT A-1 (Continued)

REMEDIATION TECHNOLOGY DESCRIPTIONS

Technologies	Description of Process
GROUND AND SURFACE WATER	
Natural Attenuation	Contaminants in an aquifer disperse and dilute through natural ground-water transport. Some natural degradation may occur.
Aeration/Air Stripping	Contaminants, usually volatile organic compounds, are transferred from liquid phase to gaseous phase. By contacting contaminated water with clean air, dissolved VOCs are transferred to the airstream to create equilibrium between the phases. The process takes place in a cylindrical tower packed with inert material which allows sufficient air/water contact to remove volatiles from water. Contaminants are then removed from the airstream.
Filtration	Filtration removes suspended solids from liquids by passing the mixture through a porous medium.
Sedimentation	Solids that are more dense than liquid settle by gravity and can be removed from the liquid. Chemicals to aid settling may be added. Settled solids result in a sludge which may be treated further.
Granular Activated Carbon (GAC) Adsorption	GAC is packed in vertical columns, and contaminated water flows through it by gravity. GAC has a high surface area to volume ratio, and many compounds readily bond to the carbon surfaces. Contaminants from water are thus adsorbed to the carbon, and effluent water has a lower contaminant concentration. Water may be passed through several of these columns to complete contaminant removal. Spent carbon (i.e., carbon that has reached its maximum adsorption capacity) is regenerated by incineration.
Ion Exchange	As contaminated water flows through the reactor vessel, ions of contaminants are adsorbed to a synthetic resin in the vessel. The resin attracts and adsorbs contaminant ions, while releasing non-harmful ions into the treated water.
Chemical Treatment	Chemicals can be added to contaminated waters to chemically change or to remove constituents. Precipitation can be accomplished through pH control; solutions can be neutralized; contaminants can be oxidized; and solids can be settled out of solution.
Biological Treatment	Microorganisms in controlled-environment reactors are utilized to decompose contaminants in water. Nutrients, pH, temperature, and oxygen availability are controlled. The organisms degrade contaminants into simpler, safer compounds.

EXHIBIT A-1 (Continued)

REMEDIATION TECHNOLOGY DESCRIPTIONS

Technologies	Description of Process
Membrane Separation	
Reverse Osmosis	A semi-permeable membrane is used to separate dissolved contaminants from liquids. High pressure is applied to the contaminated solution, which drives only the liquid through the membrane. The result is a highly concentrated contaminated solution on the high pressure side of the membrane, and a purified liquid on the opposite side of the membrane.
Electrodialysis	This process concentrates ionic species that are in aqueous solution. The solution is passed through alternate cation-permeable and anion-permeable membranes that have an applied electric potential. This potential provides a driving force for ion migration

EXHIBIT A-2

REMEDIATION TECHNOLOGIES AND SOME POTENTIALLY SIGNIFICANT RELEASES

Technologies	Air	Water*	Other[b]
SOIL AND SLUDGE TECHNOLOGIES			
Soil Handling			
Soil Excavation, Transport, Dumping, Screening and Grading	• Fugitive emissions of particulates and volatiles	• Runoff or leaching of contaminants to surface or ground water	• Seepage or runoff to nearby soil
Thermal Destruction			
Incineration: Rotary Kiln, Fluidized Bed, Circulating Bed, and Infrared	• Fugitive and stack emissions of metal fumes; particulates, including metals and salts; and products of incomplete combustion, including organic compounds, acid gases, CO, NO_x and SO_x	• Discharge of scrubber liquor and blowdown	• Disposal of ash and other solid residues
Pyrolysis	• Fugitive and stack emissions of metal fumes; particulates, including metals and salts; and products of incomplete combustion, including organic compounds, acid gases, CO, NO_x and SO_x	• Discharge of scrubber liquor and blowdown	• Disposal of ash and other solid residues
Wet Air Oxidation	• Fugitive emissions of volatile organic compounds	• Discharge of metals and unoxidized organics	• Disposal of sludge residues
Aqueous Thermal Decomposition	• Fugitive emissions of volatile organic compounds	• Discharge of metals and unoxidized organics	• Disposal of sludge residues

(Continued)

REMEDIATION TECHNOLOGIES AND SOME POTENTIALLY SIGNIFICANT RELEASES

Technologies	Air	Water*	Other[b]
Dechlorination			
Glycolate Dechlorination	• Fugitive emissions of volatile organic compounds	• Discharge of spent solvents and degraded contaminants to surface water, or leaching to ground water	
Biological Treatment			
Composting	• Fugitive emissions of particulates and volatile organics	• Leaching of metals and/or organics	
In-situ Biodegradation	• Fugitive emissions of volatile organics	• Leaching of metals and/or organics • Discharge of treated water	
Slurry-phase or Solid-phase Biodegradation	• Fugitive emissions of volatile organics	• Discharge of non-degraded byproducts in slurry liquor and treated effluent • Runoff to surface water or to ground water (with solid-phase process)	• Disposal of residual biomass which may contain hazardous metals and refractory organics
Vacuum/Vapor Extraction, Thermal Desorption			
Low Temperature Thermal Stripping	• Stack emissions of volatile organics • Fugitive emissions of volatile organics	• Discharge of scrubber blowdown • Discharge of contaminant condensate	
In-situ Vacuum/Steam Extraction	• Fugitive emissions of volatile organics	• Discharge of contaminant or water condensate	• Disposal or regeneration of spent activated carbon

REMEDIATION TECHNOLOGIES AND SOME POTENTIALLY SIGNIFICANT RELEASES

Technologies	Air	Water[*]	Other[b]
Chemical Extraction & Soil Washing			
In-situ Chemical Treatment	• Fugitive emissions of volatile organic compounds	• Runoff of uncontained treatment chemicals	• Possible solvent residuals in treated soil
Chemical or Solvent Extraction	• Fugitive emissions of volatile organic compounds	• Post-extraction discharge of wastewater with extracted contaminants	• Possible solvent residuals in treated soil
Soil Washing	• Fugitive emissions of volatile organic compounds	• Post-washing discharge of wastewater with extracted contaminants	• Discharge of foam with metals and organics • Deposition of sedimentation sludge residuals • Deposition of untreated, contaminated fines
In-situ Soil Flushing	• Fugitive emissions of volatile organic compounds	• Leaching of contaminated flush water, acids, bases, chelating agents, or surfactants	
Immobilization			
Capping	• Fugitive emissions of particulates and volatiles during cap construction	• Leaching of contaminants to ground water	• Lateral movement of volatile organic compounds after capping
Solidification/Stabilization	• Fugitive emissions of particulates and volatiles	• None likely	• Potential leaching to soils and ground water of contaminants from deposited material over time

-9-

REMEDIATION TECHNOLOGIES AND SOME POTENTIALLY SIGNIFICANT RELEASES

Technologies	Air	Water[*]	Other[b]
In-situ Vitrification	• Surface fugitive emissions of volatile organics and volatile metals during the process	• Discharge of scrubber solution • Possible contamination of ground water under the treatment area	• Potential lateral migration of vaporized or leached contaminants into the soil that surrounds the vitrified monolith
GROUNDWATER AND SURFACE WATER TECHNOLOGIES			
Non-Treatment Actions			
Natural Attenuation	• Emissions of volatile organic compounds	• Aquifer discharge to surface water • Continued aquifer transport of contaminants	
Pump without Treatment	• Emissions of volatile organic compounds	• Discharge of untreated water to surface water or Publicly Owned Treatment Works (POTW) • Seepage of untreated water	• Disposal of sludge residuals from POTW
Air Stripping	• Stack and fugitive emissions of volatile organics	• Discharge to surface water of effluent treated water with residual metals, particulates, or nonvolatile organics	• Disposal of backwash or cleaning residues
Filtration/Settling	• Fugitive emissions of volatile organic compounds from settling basin	• Discharge of effluent water containing dissolved solids or unremoved particles	• Disposal of filter cake or sludge containing organics, metals, or other inorganics
Granular Activated Carbon Adsorption	• None likely	• Discharge of effluent with non-adsorbable, low molecular weight compounds	• Disposal and/or regeneration of spent carbon

(Continued)

-40-

REMEDIATION TECHNOLOGIES AND SOME POTENTIALLY SIGNIFICANT RELEASES

Technologies	Air	Water[a]	Other[b]
Ion Exchange	• None likely	• Discharge of backwash water	• Disposal and/or regeneration of spent resins
Chemical Treatment	• Fugitive emissions of volatile organic compounds from treatment tanks	• Discharge of effluent with treatment residues	• Disposal of treatment sludges
Biological Treatment	• Emissions of volatile organics in aerobic treatment or due to aeration	• Discharge of effluent with unremoved solids	• Disposal of treatment sludges
Membrane Separation			
Reverse Osmosis	• None likely	• Discharge of effluent containing unfiltered organics (depends on filter membrane used)	• Discharge of concentrate stream with contaminants removed from treated water
Electrodialysis	• None likely	• Discharge of treated effluent	• Discharge of concentrate stream with contaminants removed from treated water

Notes:

[a] In general, seepage and leaching are more likely to affect ground water, but could also contaminate surface water. Runoff and discharge are releases that will most likely contaminate surface water, but could also contaminate ground water.

[b] Other releases include treatment residuals that need further treatment or proper disposal. In most cases, this column refers to sludge or solid residues that may also be hazardous.

REFERENCES FOR APPENDIX A

Peavy, Howard S., Donald R. Rowe, and George Tchobanoglous. 1985. *Environmental Engineering*. McGraw-Hill, New York.

U.S. Environmental Protection Agency (EPA). 1987. *A Compendium of Technologies Used in the Treatment of Hazardous Wastes*. Center for Environmental Research Information. EPA/625/8-87/014 (NTIS PB90-274093/XAB).

EPA. 1988. *Technology Screening Guide for Treatment of CERCLA Soils and Sludges*. Office of Research and Development. EPA/540/2-88/004 (OSWER Directive 9380.0-25, NTIS PB89-132674).

EPA. 1989. *Summary of Treatment Technology Effectiveness for Contaminated Soil*. Office of Emergency and Remedial Response. EPA 540/2-89/-53.

EPA. 1990. *National Technical Guidance Series. Air/Superfund Manual. Volume 3*. Office of Air Quality Planning and Standards. EPA-450/1-89-003 (NTIS PB89 180061/AS).

EPA. 1990. *The Superfund Innovative Technology Evaluation Program, Progress and Accomplishments Fiscal Year 1989*. Office of Solid Waste and Emergency Response. EPA/540/5-90/001 (NTIS PB90-216516/XAB).

EPA. 1991. Comments from Laurel Staley, Ed Bates, Ron Lewis, Teri Shearer, John Herrmann, Paul dePercin, Ed Barth. Coordinated by Mary Gaughan, Superfund Technology Demonstration Group, Cincinnati, Ohio.

APPENDIX B

QUANTIFYING POTENTIAL RELEASES FROM SELECTED REMEDIATION TECHNOLOGIES

Remediation activities at hazardous waste sites have the potential to cause emissions and impacts in addition to those being addressed. Potential emission sources during remediation include point sources of treatment residuals such as incinerator stacks; fugitive emissions from treatment equipment leakage; and areal sources of volatile organics and fugitive dusts from the disturbed surface of a contaminated land area. Uncontrolled releases can result in exposures to contaminants in soils, surface water, ground water, and ambient air surrounding the treatment equipment. The following sections provide descriptions of several common remediation activities to serve as examples of the considerations involved in quantifying technology-specific releases. This appendix also contains a list of references that can be useful in quantifying potential air releases for a variety of remediation technologies.

B.1 SOILS HANDLING TECHNOLOGIES

Soils handling is a major component of nearly all ex-situ technologies for treating contaminated soils. Soil handling activities include: excavation; transportation (e.g., to storage or treatment areas); dumping (e.g., onto trucks or piles); storage; and grading the treated or replaced soil. Any or all of these activities may result in fugitive dust emissions, the main type of release from soils handling. These emissions can carry organic and/or inorganic contaminants, which may be bound to soil particles, for great distances away from the site. Soil handling activities also can increase volatile organic emissions by exposing contaminated soil to the atmosphere, and through agitation of the soil.

Some of the important parameters that may affect the fugitive dust emissions potential at a contaminated site are listed in the box below. These parameters depend on site and remedial activity characteristics. Details can be obtained from onsite observation or from vendors and/or

operators. Some or all of these parameters may already have been considered in the RI/FS. Fugitive dust emission factors (mass per unit operation) or rates (mass per unit time, derived from emission factors) for volatile organic, particulate and/or metal contaminants during each soil handling remedial activity can be estimated using equations and procedures outlined in the documents listed in Section B.4. These emission factors or rates can be used as inputs to fate and transport models, which are used to generate exposure point concentrations. Additional information on exposure assessment can be obtained from Chapter 2 of this guidance and Chapter 6 of RAGS/HHEM Part A.

KEY PARAMETERS AFFECTING RELEASES FROM SOILS HANDLING

- Area of working surface
- Agitation factor
- Drop height (when transferring soil)
- Storage pile geometry
- Soil moisture content
- Soil silt content
- Meteorological conditions
- Chemical characteristics

B.2 THERMAL DESTRUCTION TECHNOLOGIES

Thermal destruction uses high temperature and controlled conditions to oxidize and/or degrade a substance into simple combustion products such as CO_2, H_2O vapor, SO_2, NO_x, HCl gases, and ash. Thermal destruction methods can be used to destroy organic contaminants in liquid, gaseous, and solid waste streams. Incinerators are by far the best known and most studied thermal destruction devices. In many cases, thermal destruction techniques that do not have sufficient

emission data can be assumed to have emission characteristics similar to incinerators.

Emission sources from incinerators include process emissions and fugitive emissions. Incinerator process emissions include stack gas, bottom ash, and air pollution control device residuals. Fugitive emissions include uncontrolled or undetected equipment leakage. Process emission estimation methods for organic compounds, metals, particulates, and acid gases (HCl, SO_2, and HF) can be obtained from EPA (1985a) (see Section B.4.1). Fugitive emission sources and equations for estimating emissions are detailed in EPA (1989) (see Section B.4.1) and Holton and Travis (1984) (see Section B.4.3). Fugitive emissions from soils handling prior to incineration can be estimated using the guidance given in Section B.1 on soils handling.

Emissions from thermal destruction technologies generally can be estimated using any one of the approaches listed below. (These methods do not directly account for removal of contaminants by air pollution control devices that may be used to treat emissions from thermal destruction devices.)

- **Default approach:** Thermal destruction devices at most contaminated sites may be required to meet the requirements under federal regulations such as RCRA or the Toxic Substances Control Act (TSCA), since these requirements are generally considered ARARs. RCRA requires at least 99.99% destruction and removal of regulated organic constituents from wastes. TSCA requires 99.9999% destruction and removal for wastes containing PCBs and dioxins. Thus, organic emissions from thermal destruction of hazardous waste can be estimated by assuming that the above requirements of RCRA and TSCA will be exactly met, for pollutants covered by those regulations. Similar requirements can be used to estimate HCl emissions, but this approach may not provide estimates for particulate or air emissions.

- **Trial run approach:** Federal regulations such as RCRA and TSCA require trial burns to demonstrate removal efficiencies. Whenever trial burn data for the waste in question exist they can be used to estimate the emissions that might occur during actual remedy implementation. Data obtained from trial

burns at different sites or different operating units from the same site can be used for estimating emissions.

- **Theoretical or empirical approach:** Theoretical or applicable empirical equations — often called models — can be used to estimate emissions. These models correlate incinerator operating parameters and pollutant emission rates.

Some of the important parameters that may affect the emissions associated with thermal destruction technologies are listed in the box below. Many of these parameters are device dependent and can be obtained from onsite observation or from vendors and/or operators.

KEY PARAMETERS AFFECTING RELEASES FROM THERMAL DESTRUCTION

- Waste feed rate
- Burn temperature
- Residence time
- Excess air rate
- Facility size/type
- Atomization
- Control device efficiency
- Chemical characteristics

B.3 SOLIDIFICATION/ STABILIZATION TREATMENT TECHNOLOGIES

Solidification/stabilization technologies are used to immobilize the toxic and hazardous constituents in the waste by changing those constituents into immobile forms, binding them in an immobile, insoluble matrix, and/or binding them in a matrix that minimizes the material surface exposed to solvents. Except for emerging technologies that involve in-situ treatment, the implementation of stabilization or solidification generally involves several of the soils handling activities discussed in Section B.1. The box below lists some of the key parameters affecting releases associated with solidification/stabilization. These parameters depend on the specific

solidification/stabilization process. These can be obtained from onsite observation or from vendors and/or operators.

KEY PARAMETERS AFFECTING RELEASES FROM SOLIDIFICATION/STABILIZATION TREATMENT TECHNOLOGIES

- Binder type
- Batch size
- Waste/binding agent ratio
- Mixing time/efficiency
- Curing time
- Meteorological conditions
- Chemical characteristics

B.4 REFERENCES FOR DETERMINING RELEASES RESULTING FROM REMEDIAL ACTIVITIES

Provided below are references containing discussions of remedial activities and methodologies for determining releases associated with these activities. The references presented under the heading of various remedial activities contain information regarding the majority of remedial activities that may occur at a site (including soils handling, thermal destruction, and stabilization/solidification). The remaining references contain information specific to the activity listed in the heading. See the references provided for the main text of RAGS/HHEM Part C, especially the RI/FS Guidance (EPA 1988c), for additional references.

B.4.1 VARIOUS REMEDIAL ACTIVITIES

Primary References

Environmental Protection Agency (EPA). 1985a. *Handbook: Remedial Action at Waste Disposal Sites* (Revised). Hazardous Waste Engineering Research Laboratory. EPA/625/6-85/006 (NTIS PB87-201034/XAB).

Provides information on remedial technologies, selection of appropriate remediation technologies for a given waste site, and planning remedial activities. Includes

discussions of onsite and offsite disposal of wastes and soil, removal and containment of contaminated sediments, and in-situ treatments.

EPA. 1989. *Estimation of Air Emissions from Cleanup Activities at Superfund Sites.* Air/Superfund National Technical Guidance Study Series, Volume 3. Office of Air Quality Planning and Standards. EPA/450/1-89/003 (NTIS PB89-180061/XAB).

This document provides a step-by-step protocol for estimating air quality impacts resulting from site remediation. Presents emissions estimation techniques for thermal destruction devices, air stripping of ground water, in-situ venting, soils handling, and solidification/stabilization.

Additional References

EPA. 1990. *Emission Factors for Superfund Remediation Technologies.* Draft. Office of Air Quality Planning and Standards.

EPA. 1988. *Superfund Removal Procedures Revision Number Three.* Office of Emergency and Remedial Response. OSWER Directive 9360.03B.

EPA. 1986. *Superfund Remedial Design and Remedial Action Guidance.* Office of Emergency and Remedial Response. OSWER Directive 9355.0-4A.

B.4.2 SOILS HANDLING

Primary References

EPA. 1985b. *AP-42: Compilation of Air Pollution Emission Factors.* Fourth Edition. Office of Air and Radiation. NTIS PB86-124906.

This document contains emissions data obtained from source tests, material balance studies, engineering estimates, and other sources. Emission factors and equations are derived from sand and gravel processing (Section 8.19.1), crushed stone operations (Section 8.19.2), surface coal mining (Section 8.2.4), and fugitive dust sources (Section 11.2)

EPA. 1985c. *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites.* EPA/600/A-85/002.

This document provides a methodology for rapid assessment of inhalation exposures to respirable particulate emissions from surface contaminated sites. The methodology consists of a site survey procedure and particulate emission factor equations for wind and mechanical entrainment processes.

EPA. 1990. *Development of Example Procedures for Evaluating the Air Impacts of Soil Excavation Associated with Superfund Remedial Actions.* Office of Air Quality Planning and Standards. EPA/450/4-90/014 (NTIS PB90-255662XAB).

This document identifies and defines computational requirements for estimating air impacts from remediation of CERCLA sites. The estimation of air impacts from two example sites employing soil excavation are discussed. Modified Research Triangle Institute (RTI) land treatment equations are used for calculating emissions from excavations.

Additional References

Baxter, R.A. and D.M. Wilbur. 1983. *Fugitive Particulate Matter and Hydrocarbon Emission Factors from Mining, Handling, and Storing Diatomite.* AeroVironment, Inc. Pasadena, California.

EPA. 1977. *Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions.* Office of Air Quality and Planning Standards. EPA/450/3-77/010 (NTIS PB-272 288/2).

EPA. 1985d. *Modeling Remedial Actions at Uncontrolled Hazardous Waste Sites.* Office of Emergency and Remedial Response. Office of Solid Waste and Emergency Response. EPA/540/2-85/001 (OSWER Directive 9355.0-8).

Orlemann, J.A. and G.A. Jutze. 1983. *Fugitive Particulate Dust Control Technology.* Noyes Publications. Park Ridge, New Jersey.

B.4.3 THERMAL DESTRUCTION

Primary References

Holton, G.A. and C.C. Travis. 1984. Methodology for Predicting Fugitive Emissions for Incinerator Facilities. *Environmental Progress* 3:2. Oak Ridge National Lab., Health & Safety Research Division. Oak Ridge, TN.

Error analysis and Monte Carlo modeling techniques are used to predict fugitive emissions caused by leaky pump fittings, sampling connections, flanges, storage tanks, and other non-stack equipment. Ten equations and three parameter value tables are provided for emission calculations.

Travis, C.C., E.L. Etnier, G.A. Holton, F.R. O'Donnel, and D.M. Hetrick. 1984. *Inhalation Pathway Risk Assessment of Hazardous Waste Incineration Facilities.* Oak Ridge National Lab. Oak Ridge, Tennessee. ORNL/TM-9096.

This report evaluates the relative importance of plant design and waste physicochemical variables on human inhalation exposure and health risk using two hypothetical incineration facility designs of three sizes each, burning three different generic wastes. Fugitive emissions are calculated using equations relating incinerator facility operation and configuration to fugitive emissions.

Trenholm, A. and D. Oberacker. 1985. "Summary of Testing Program at Hazardous Waste Incinerators." *Proceedings — Annual Solid Waste Research Symposium.* Environmental Protection Agency. Cincinnati, Ohio. Report No. CONF-8504112.

This article summarizes the results of tests conducted at eight full-scale hazardous incineration facilities.

Additional References

Cheremisinoff, P.N. 1986. "Special Report: Hazardous Materials and Sludge Incineration." *Journal of the Air Pollution Engineering* 18:12(32-38).

EPA. 1984. *Performance Evaluation of Full-scale Hazardous Waste Incinerators.* (Five volumes.) Industrial Environmental Research Laboratory. Cincinnati, OH. EPA-600/2-84-181 a-e (NTIS PB85-129500).

Lee, C.C., G.L. Huffman, and D.A. Oberacker. 1986. "Hazardous/Toxic Waste Incineration." *Journal of the Air Pollution Control Association* 36:8.

Oppelt, E.T. 1987. "Incineration of Hazardous Waste. A Critical Review." *Journal of the Air Pollution Control Association.* 37:5.

Staley, L.J., G.A. Holton, F.R. O'Donnel, and C.A. Little. 1983. "An Assessment of Emissions from a Hazardous Waste Incineration Facility. Incineration and Treatment of Hazardous Waste." *Proceedings of the Eighth Annual Research Symposium.* EPA-600/9-83/003.

Wallace, D.D., A.R. Trenholm, and D.D. Lane. 1985. "Assessment of Metal Emissions from Hazardous Waste Incinerators." *Proceedings — 78th APCA Annual Meeting.* Paper 85-77. Air Pollution Control Association. Pittsburgh, Pennsylvania.

B.4.4   STABILIZATION/SOLIDIFICATION

Primary References

Cullinane, M.J., L.W. Jones, and P.G. Malone. 1986. *Handbook for Stabilization/Solidification of Hazardous Waste.* Hazardous Waste Engineering Research Laboratory. EPA 540/2-86/001.

Hill, R.D. 1986. *Stabilization/Solidification of Hazardous Waste.* Hazardous Waste Engineering Research Lab. EPA/600/D-86/028.

This document discusses techniques such as sorption, lime-fly ash Pozzolan process, Pozzolan-Portland process, thermoplastic microencapsulation, and other techniques.

Additional References

Cullinane, M.J. and L.W. Jones. 1985. *Handbook for Stabilization/Solidification of Hazardous Waste.* Prepared for: Environmental Protection Agency, Hazardous Waste Engineering Research Laboratory. Office of Research and Development. EPA/540/2-86-001.

APPENDIX C

SHORT-TERM TOXICITY VALUES

The short-term effectiveness criterion for evaluating remedial alternatives includes an evaluation of the risks due to the short-term exposure of populations to contaminants during remedy implementation. Such short-term risks generally include both baseline risks from existing site contamination and new risks that would occur during the implementation of a remedy. In some cases, potential exposures and risks due to short-term exposures should be quantitatively assessed; however, there is no simple or widely accepted method for estimating such risks. Therefore, in all cases where short-term toxicity values are needed, TSC should be consulted. EPA's Environmental Criteria and Assessment Office (ECAO; where TSC is located) will maintain the data files for the most appropriate short-term toxicity values for evaluating risks from remedial alternatives. To obtain the most up-to-date information, regional EPA CERCLA staff must contact:

Superfund Health Risk Technical
  Support Center
Environmental Criteria and Assessment Office
U.S. Environmental Protection Agency
Mail Stop 114
26 West Martin Luther King Drive
Cincinnati, OH 45268
Phone: 513-569-7300 (FTS-684-7300)
FAX: 513-569-7159 (FTS-684-7159)

Requests from others must be submitted to the TSC in writing and must contain the following information for consideration:

- CERCLA site name, site location, and 12-digit site number;

- name and phone number of the RPM; and

- detailed description of the risk assessment related question.

The remainder of this appendix provides some general background on exposure duration issues and an overview of some of the existing methods

for deriving short-term human health toxicity values.

C.1   BACKGROUND ON EXPOSURE DURATION

In assessing short-term risks of remedial alternatives, the time frame (e.g., hours, days, weeks up to seven years) is generally of a much shorter duration than that identified in the baseline risk assessment. Nevertheless, there are a number of types of toxicity values that have been developed to characterize risk due to these short-term exposures. Some of these types depend on concentration- or dose-based threshold limits that are used as guidance levels for protection of specific populations from specific exposures (e.g., guidance levels intended to protect healthy workers from daily occupational exposure to chemicals in the workplace). In this section, the types of exposure durations commonly suggested or implied by the toxicity value types (discussed later) are presented.

Releases that may occur during remedy implementation could last for varying durations but are expected, in most if not all cases, to give rise to less-than-lifetime exposures. Furthermore, releases that occur during remediation may result in exposure levels much higher than those preceding remediation. Different risk levels may be associated with these different exposure durations (assuming the same dose rate) and with various exposure concentrations. Therefore, it is important that the dose- or concentration-based toxicity values that are chosen to characterize the short-term risks be based on appropriate exposure durations. Exposure durations associated with existing methods for characterizing short-term risks include hours, days, weeks, months, and years (generally up to seven years).

Currently, RAGS/HHEM Part A defines three exposure durations, apart from long-term exposure, that may be of concern at CERCLA sites: single

exposure event, very short-term exposure, and short-term (subchronic) exposure.

- **Single Exposure Event.** The majority of chemicals are capable of producing an adverse health effect after a single exposure event, depending on the intensity of exposure. For developmental toxicants, irritants, and neurological poisons, a single, low level exposure event can result in effects after minutes, hours, or a day.

- **Very Short-term Exposure.** For some acute toxicants, multiple exposures over several days could result in an adverse effect. For these chemicals, the exposure is assessed over days or weeks (up to two weeks).

- **Short-term (Subchronic) Exposure.** Exposure lasting anywhere from two weeks to seven years to low concentrations of a chemical can also produce adverse effects; this exposure is assessed by averaging it over the specific duration.

During evaluations of remedial alternatives, it may be important to assess exposure (and risk or hazard) for all relevant exposure durations. Both the shortest time period of exposure, from peak or accidental releases, to the cumulative exposure over the entire time period of the remedy implementation, may need to be considered. Quantitative assessment is contingent, however, upon the availability of adequate exposure characterization. Exposure models used to predict concentrations have not for the most part been validated over the short durations considered for single exposure events (e.g., minutes to hours). At best, meteorological data are collected on an hourly basis at a site removed from the location of interest; using these data to derive a model to predict exposure concentrations for durations shorter than those for the meteorological data may produce results that could not be supported scientifically. In addition, the need to evaluate peak exposures as well as longer-term average exposures during remedy implementation depends on a number of considerations, including the degree of risk or hazard associated with the longer-term exposure and the difference between the predicted peak and average exposure concentrations.

A review of the types of (duration-specific) toxicity values that are available (discussed later in this appendix) indicates that a number of the types correspond to various durations that are relevant to releases during remedy implementation. Because a toxicity value generally is specific to a certain duration, however, risk may need to be characterized separately for the three short-term exposure durations.

C.2 EXISTING SHORT-TERM TOXICITY VALUES

In this section, commonly encountered short-term toxicity values are summarized. These values are: (1) concentration and dose threshold values primarily for noncarcinogenic effects; and (2) specific short-term carcinogenic risk values. A section is provided on each of these toxicity value categories.

C.2.1 TOXICITY VALUES FOR ASSESSING RISK OF NONCARCINOGENIC EFFECTS FOR SHORT-TERM EXPOSURE

Toxicity values designed to characterize the risk of noncarcinogenic effects are summarized in the following subsections. Further information on the suitability of these values for various CERCLA exposure scenarios can be obtained from the TSC.

C.2.1.1 Developmental Toxicant Reference Dose (RfD_{dt}) and Reference Concentration (RfC_{dt})

RfD_{dt}s and RfC_{dt}s are developed for chemicals that have been shown to cause adverse effects in a developing organism. EPA's Human Health Assessment Group of the Office of Health and Environmental Assessment is in the process of developing RfD_{dt} and RfC_{dt} values and the methodology for their derivation. As proposed by EPA (EPA 1989b), these values will likely be derived from the no-observed-adverse-effect-level (NOAEL) or lowest-observed-adverse-effect-level (LOAEL) in a manner consistent with the derivation of reference doses (RfDs) and reference concentrations (RfCs), and without adjustment for short exposure duration. RfD_{dt}s are expressed in terms of dose and RfC_{dt}s are expressed as an air concentration. Additional information on these criteria is available in EPA's Proposed Amendments to the Guidelines for the Health Assessment of Suspected Developmental Toxicants (EPA 1989b), or by contacting the Reproductive

and Developmental Toxicology Branch of the Office of Health and Environmental Assessment at 202-260-7331 (FTS-260-7331).

Currently (i.e., at the date of publication of this guidance), developmental toxicity is considered in the derivation of EPA criteria for noncarcinogenic effects (including RfDs and RfCs for subchronic and chronic exposure and drinking water Health Advisories [HAs]). That is, these criteria are set at levels considered protective for developmental effects as well as for other noncarcinogenic effects.

C.2.1.2 Subchronic Reference Dose (RfD$_s$) and Reference Concentration (RfC$_s$)

RfD$_s$s and RfC$_s$s are developed by ECAO and are used to characterize potential noncarcinogenic effects associated with short-term exposures (two weeks to seven years as defined in RAGS/HHEM Part A). To date, approximately 305 RfD$_s$s and 60 RfC$_s$s have been published. These RfDs and RfCs are developed based on NOAELs or LOAELs identified from subchronic (i.e., usually ≥ 90 days but less-than-chronic) toxicity studies. RfD$_s$s are expressed in terms of dose and RfC$_s$s are expressed as air concentrations. Subchronic RfDs and RfCs are available in HEAST. The derivation of RfD$_s$s is described in more detail in RAGS/HHEM Part A.

C.2.1.3 One-day, Ten-day, and Longer-term Drinking Water Health Advisories (HAs)

Drinking water HAs developed by EPA provide guidance to assist state and local officials responsible for public health protection during emergency situations involving drinking water contamination. HAs are derived in a manner reasonably consistent with oral RfD methodology. Accordingly, these HA values constitute suitable criteria for evaluating short-term oral exposure. The HA concentrations include a margin of safety to protect sensitive members of the population (e.g., children, the elderly, pregnant women). "One-day HA" is the term used to describe the concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects for one day of exposure, with a margin of safety. The "Ten-day HA" describes the concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic health effects for two to ten consecutive days of exposure, with a margin of

safety. The "Longer-term HA" is the concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects up to approximately seven years of exposure. ("Lifetime HAs" that are protective for exposure over a lifetime are also developed based on chronic RfDs.)

In general, the HAs described here are protective of only noncarcinogenic effects. These values are expressed as concentrations in drinking water but can be converted to mg/kg/day doses by using the assumptions that were applied in their calculation: consumption of 1 L/day by a 10 kg child (one-, ten-, and longer-term HAs) and 2 L/day by a 70-kg adult (lifetime HA). Approximately 140 HAs have been developed by EPA for each exposure duration. (HAs are briefly described in RAGS/HHEM Part A.)

C.2.1.4 Acute Inhalation Criteria (AIC)

A report describing the derivation of AICs for benzene and beryllium is available through the TSC. AICs are derived as criteria for single, short-duration (up to an hour or a few hours) inhalation exposures, as may occur from releases during remediation. The AICs are based on noncancer endpoints and are expressed as air concentrations. AICs have been derived for a limited number of chemicals using EPA RfC methodology, modified as required for this acute exposure scenario. The modification consists of using the NOAEL (or LOAEL) as reported in the study without adjustment for exposure duration (hours/24 hours). Because these criteria are conceptually consistent with inhalation RfCs, they are a good basis for assessing short-term risks from single, very short exposures. The TSC should be contacted for additional AIC values.

C.2.1.5 Minimal Risk Levels (MRLs)

MRLs are derived by the Agency for Toxic Substances and Disease Registry (ATSDR) from human or animal studies for threshold effects on chemicals found at CERCLA hazardous waste sites. MRLs are developed for both inhalation and oral exposures; oral MRLs are expressed as doses and inhalation MRLs are expressed as concentrations in air. Estimates of exposure posing minimal risk to humans are made for the most sensitive noncarcinogenic endpoint (including developmental and reproductive endpoints) for three different exposure durations (i.e., acute,

intermediate, and chronic). These exposure durations for which MRLs are derived are as follows: acute MRL — 1 to 14 days; intermediate MRL — 15 to 364 days; chronic MRL — ≥ 365 days. MRLs are developed using an approach that is consistent with EPA RfD methodology (i.e., identification of a NOAEL or LOAEL and application of uncertainty factors to reflect human variability and, where appropriate, the uncertainty of extrapolating from laboratory animal data to humans).

Acute inhalation MRLs differ from AIC in regard to adjustment for exposure duration. The guidance for derivation of acute inhalation MRLs specifies that "exposure periods of less than 24 hours in the toxicity study from which the MRL is derived, can be adjusted to one day" (ATSDR 1991); this adjustment is commonly carried out. No such adjustment is carried out in the derivation of AICs, which are intended to serve as guidance for acute, very short, and single exposures (e.g., ranging from less than an hour to a few hours, perhaps as inadvertent releases during remediation).

MRLs can be found in the ATSDR Toxicological Profile documents in the Health Effects Summary section, on the Levels of Significant Exposure figure (graph). The bottom of the dotted line on the graph represents the MRL. Except in the earliest ATSDR Toxicological Profiles, MRL values and the endpoints on which they are based are also identified in the text accompanying the figure. To date, approximately 62 acute MRLs (38 oral, 24 inhalation) have been derived by ATSDR. As with other short-term toxicity values, guidance regarding use of the MRL must be sought from the TSC.

C.2.1.6 Emergency Exposure Guidance Level (EEGL), Short-term Public Emergency Guidance Level (SPEGL), and Continuous Exposure Guidance Level (CEGL)

EEGLs and CEGLs are exposure guidance levels developed by the National Research Council (NRC 1986) specifically for military personnel operating under emergency conditions. Therefore, setting of these levels involves consideration of various factors (such as age distribution, length of exposure, and susceptibility) that are different from those related to the general population. These guidance levels are published in the NRC (1984-

1988) *Emergency and Continuous Exposure Guidance Levels for Selected Airborne Contaminants*. To date, 43 chemicals have been evaluated by NRC.

The EEGL is defined as the air concentration of a substance that is acceptable for the performance of specific tasks during rare emergencies usually lasting from 1 to 24 hours (i.e., it is a ceiling guidance level for a single emergency exposure) (NRC 1986). EEGLs are intended to prevent irreversible harm or serious impairment of judgment or performance. Exposure at an EEGL might produce reversible effects, and therefore should not be considered hygienic or safe. Acute toxicity is the primary basis for establishing an EEGL. However, even brief exposure to some substances might have the potential to increase the risk of cancer or other delayed effects. Derivation of an EEGL may involve application of an uncertainty factor of ten to extrapolate from animal data to humans, but no other species adjustments are applied. Some EEGLs are based on extrapolation of oral data. EEGLs are based on the most sensitive or most important noncarcinogenic health effects known. Because EEGLs are derived for healthy military personnel during rare emergencies, and are not intended to protect against reversible effects, they should not be applied directly to the general population (NRC 1986).

The SPEGL is defined as a suitable concentration for unpredicted, single, short-term emergency exposure of 1 to 24 hours of the general public. SPEGLs take into account the wide range of susceptibility of the general public. The SPEGL is generally estimated by applying an uncertainty factor of two to ten to the EEGL, to account for sensitive groups — such as children, the elderly, and persons with serious debilitating diseases. NRC (1986) suggests that a safety factor of two (i.e., EEGL x 0.5) is appropriate to protect more sensitive groups, such as children or the elderly, and that a safety factor of ten (i.e., EEGL x 0.1) is appropriate for fetuses or newborns. Because the SPEGL is derived from the EEGL, the considerations discussed above with regard to the EEGL also apply to SPEGLs.

The CEGL is defined as a ceiling concentration of a chemical in air to which military personnel can be exposed for up to 90 days without immediate or delayed adverse effects or degradation of performance (NRC 1986). CEGLs

-52-

are not derived for carcinogens. When data from chronic studies are available, they can be used to derive CEGLs. A CEGL is generally estimated, however, by applying an uncertainty factor of 10 to 100 to the EEGL (i.e., EEGL x 0.01 to 0.1), depending on the evidence for detoxification or accumulation of the substance in the body. Where there is evidence of substantial detoxification, a safety factor of ten is recommended by NRC (1986). If there is no evidence of detoxification or detoxification is slow, a safety factor of 100 might be more appropriate. If the substance accumulates in tissues, such as halogenated biphenyls and metals, even higher factors are recommended by NRC (1986). Other considerations discussed with regard to the EEGL also apply to CEGLs derived from EEGLs.

C.2.1.7   Threshold Limit Values -- Short-term Exposure Limits (TLV-STELs), Threshold Limit Values — Time-weighted Averages (TLV-TWA), and Threshold Limit Values — Ceiling (TLV-C)

TLVs are concentrations developed by the American Conference of Governmental Industrial Hygienists (ACGIH) to protect workers from adverse effects of occupational exposure to airborne chemicals. However, because occupational exposure limits are not intended to protect sensitive workers or other populations, are not intended for the assessment of community air pollution or continuous exposure, may not incorporate the most recent toxicological data, may be based on unpublished documentation that is not available for review, and may differ from EPA derivations with respect to weight-of-evidence considerations and use of uncertainty factors, EPA does not endorse the general use of occupational exposure limits in deriving EPA criteria.   In addition, it should be noted that the TLVs for a fair number of chemicals are derived by analogy to other chemicals because health effects data are inadequate or lacking.

The TLV-STELs are 15-minute time-weighted average (TWA) exposures that should not be exceeded at any time during the eight-hour work day/40-hour work week and should not occur more than four times a day, with at least 60 minutes between successive exposures in the STEL range (ACGIH 1990). The TLV-STEL is established to prevent workers from suffering irritation, chronic or irreversible tissue damage, or narcosis of

sufficient degree to increase the likelihood of accidental injury. Use of the TLV-STEL should be limited to very short, single exposure events. STELs are recommended for substances with acute effects recognized from high short-term exposures in either humans or animals (ACGIH 1990). Approximately 115 TLV-STELs have been published by ACGIH.

The TLV-TWA is the time-weighted average concentration for a normal eight-hour workday/40-hour workweek to which nearly all workers may be exposed, day after day, without adverse effects. The TLV-C is a concentration that should not be exceeded during any part of the working exposure. The ACGIH uses the TLV-C for substances that are particularly fast acting and hence are best controlled by a ceiling limit. In excess of 500 TLV-TWAs and fewer than 50 TLV-Cs have been published by ACGIH.

C.2.1.8   Permissible Exposure Levels (PELs) and Recommended Exposure Limits (RELs)

PELs are enforceable occupational exposure standards developed by the Occupational Safety and Health Administration (OSHA).   They are meant to protect workers against catastrophic effects (such as cancer; cardiovascular, liver, and kidney damage; and lung diseases) as well as more subtle effects resulting in central nervous system damage, narcosis, respiratory effects, and sensory irritation. The PELs are generally adopted from (existing) secondary guidance levels (e.g., ACGIH's TLV-TWAs and TLV-STELs and the recommended exposure limits [RELs] developed by the National Institute for Occupational Safety and Health [NIOSH]), and nearly 400 are available from OSHA. EPA's reservations concerning the use of TLVs as the basis for criteria to protect the general population (see Section C.2.1.7) apply also to PELs and RELs.

C.2.1.9   Other Miscellaneous Methods

The following are some other methods that risk assessors or RPMs may encounter.

•   Immediately Dangerous to Life and Health (IDLH) Guidelines.   IDLH guidelines are developed by NIOSH. These air concentration limits are for 30-minute exposures under what are essentially emergency conditions, and generally far exceed corresponding TLV-TWA, TLV-STELs or PELs. IDLH guidelines were

determined only for the purpose of respirator selection. These guidelines are intended to be the maximum air concentration from which, in the event of respirator failure, a worker could escape within 30 minutes without experiencing any escape-impairing or irreversible health effects (NIOSH 1985). Many of the IDLH exposure levels are so high that they define levels at which severe toxic effects (unconsciousness, incapacitation, intolerable irritation or death) would be likely (Alexeef et al. 1989). Therefore, the IDLH guidelines are not suitable as benchmark guidelines for acute exposure and may be higher than would be useful even as a guideline for immediate evacuation.

- CERCLA Section 102(a) Reportable Quantities (RQs). RQs are developed by EPA based on, among other factors, acute toxicity, chronic noncarcinogenic toxicity, and carcinogenicity. RQs define the quantity in pounds above which a release is considered potentially hazardous (or, at least, warrants reporting) under CERCLA section 102(a). The documentation for RQs may contain health effects information that would be useful in determining criteria for short-term exposure but are not by themselves useful in characterizing risks from releases that might occur at a CERCLA site.

C.2.2 SPECIFIC CARCINOGENIC RISK VALUES FOR SHORT-TERM EXPOSURES

There is relatively little guidance available on characterizing risks from short-term exposure to carcinogens. For cancer endpoints, most of the currently available values are specific to lifetime exposure. Many experimental investigations of carcinogenicity involve high-dose, long-duration exposure to compensate for the small number of animals that are used. Carcinogenicity data on short-term or single exposures are virtually nonexistent for most chemicals. For most chemicals, the current scientific view is that any exposure, no matter how short in duration, can result in a carcinogenic risk. Characterizing this risk is complicated, however, because of factors such as age at first exposure and mechanism of the carcinogen's action. Consistent with RAGS/HHEM Part A and the Guidelines for Carcinogen Risk Assessment (EPA 1986a), the preferred approach would be to consider

cumulative dose, averaged over a lifetime. This method is discussed in Section C.2.2.1.

Several investigators have reported additional methods to characterize the effects from short-term exposure to carcinogens. Some of these methods are currently being investigated by EPA but are not recommended for short-term carcinogenic assessments at this time. However, brief summaries of these methods are provided below with documentation for the interested reader to pursue.

C.2.2.1 RAGS/HHEM Part A Method

RAGS/HHEM Part A currently recommends that lifetime average exposures always be used to estimate carcinogenic risks. That is, because the cancer toxicity values (i.e., SFs) are based on lifetime average exposures. Part A recommends that less-than-lifetime exposures be converted to equivalent lifetime values for the assessment of risk. (This is also the recommended approach in EPA's Guidelines for Carcinogenic Risk Assessment [EPA 1986].) In this manner, risks from short-term exposures would be averaged over a 70-year lifetime, with modifications for specific chemicals if appropriate, and, therefore, may appear to be relatively minor in comparison to risks from longer-term exposures. While adjusting less-than-lifetime exposure to an equivalent lifetime exposure may be valid for relatively long exposure durations, this adjustment for short-term exposures may underestimate the risk for "early-stage" carcinogens (i.e., DNA-damaging agents).

C.2.2.2 Office of Research and Development (ORD) Interim Method for Vinyl Chloride

EPA's ORD (EPA 1989a) used a study by Drew et al. (1983) to determine that the lifetime carcinogenic risk from vinyl chloride inhalation increases when exposure occurs early in life. Drew et al. showed that the effects from exposure to vinyl chloride depend on both age at initial exposure and duration of exposure. His data showed that children face higher risks than adults for exposures of a given duration. Cogliano stated that if risk for partial lifetime exposures is estimated by ignoring the age at initial exposure and considering only the duration, the risk will be underestimated for children and overestimated for adults over 30. He proposed that risk for partial

lifetime exposure to vinyl chloride be: (1) estimated as being proportional to the remaining lifetime of the exposed individual. and (2) adjusted depending on the length of exposure. The author also stated that, at this time, this analytical technique is applicable only to vinyl chloride and should not be applied to any other substances. The TSC should be contacted for further guidance on assessing risks from vinyl chloride.

C.2.2.3 EEGLs for Carcinogens

The NRC (1986) has developed a method for deriving EEGLs (1 to 24-hour exposure guidelines) for inhaled carcinogens when the computed cancer risk associated with the toxicity-based EEGL (see Section C.2.1.6) is more than one in 10,000. In these cases, the EEGL is lowered so that the risk is not more than one in 10,000 (1×10^{-4}). The NRC method draws on the analysis of Crump and Howe (1984) and appears to employ a higher level of acceptable lifetime risk (i.e., 1×10^{-4}) than the RAGS/HHEM Part A method. This method is discussed in further detail in *Criteria and Methods for Preparing Emergency Guidance Level (EEGL), Short-term Public Emergency Guidance Level (SPEGL), and Continuous Exposure Guidance Level (CEGL) Documents* (NRC 1986). The 24-hour EEGL for a carcinogen is estimated as follows:

$$EEGL = \frac{d \times 25,600}{2.8} \times \frac{R}{\text{level of risk at } d}$$

where:

d = lifetime exposure level (air concentration), as computed by a regulatory agency or by the NRC Committee on Toxicology in accordance with procedures used by regulatory agencies (multistage model) associated with "acceptable" level of cancer risk. e.g., 1×10^{-6} level of risk.

25,600 = number of days in a lifetime (25,600 days = 70 years); application of this duration factor assumes that carcinogenic effects are a linear function of the total (cumulative) dose.

2.8 = a factor to account for uncertainties regarding which stage of carcinogenesis is affected by the substance and for the likely youth of military personnel; the NRC (1986) states that "the maximal additional risk that these considerations contribute is a factor of 2.8," based on the "data of Crump and Howe (1984)," and

R = target acceptable risk level (e.g., 1×10^{-4}) for one day of exposure.

The reservations with this method concern the choice of a higher target risk level (1×10^{-4}) in combination with other assumptions of this method, and the origin of the above uncertainty factor of 2.8. The origin of this uncertainty factor is not explained adequately by NRC (1986), nor is it apparent in the cited paper (Howe and Crump 1986).

REFERENCES FOR APPENDIX C

Drew. R.T.. Boorman G.A.. Haseman J.K.. McConnell. E.E., Busey. W.M.. Moore J.A. 1983. The Effect of Age and Exposure Duration on Cancer Induction by a Known Carcinogen in Rats, Mice. and Hamsters. *Toxic. Appl. PharmacoL* 68:120-130.

Crump. K.S., Howe. R.B. 1984. The Multistage Model with a Time-dependent Dose Pattern: Applications to Carcinogenic Risk Assessment. *Risk Analysis* 4 (3): 163-176.

National Institute of Occupational Safety and Health (NIOSH). 1985. *NIOSH Pocket Guide to Chemical Hazards.* U.S. Department of Health and Human Services. Washington, DC.

Environmental Protection Agency (EPA). 1986. Guidelines for Carcinogenic Risk Assessment. 52 *Federal Register* 33992.

National Research Council (NRC). 1986. *Criteria and Methods for Preparing Emergency Exposure Guidance Level (EEGL), Short-term Public Emergency Guidance Level (SPEGL), and Continuous Exposure Guideline Level (CEGL) Documents.* Prepared by the Committee on Toxicology. National Academy Press. Washington, DC.

Alexeef. G.V., Lipsett. M.J., and Kizer. K.W. 1989. Problems associated with the use of Immediately Dangerous to Life and Health (IDLH) values for estimating the hazard of accidental chemical releases. *Amer. Ind. Hyg. Assoc. J.* 50(11):598-605.

EPA. 1989a. Internal memorandum from J. Cogliano to S. Bayard. Status of Vinyl Chloride Assessment. Office of Health and Environmental Assessment.

EPA. 1989b. Proposed Amendments to the Guidelines for the Health Assessment of Suspected Developmental Toxicants. 45 *Federal Register* 9386-9403.

American Conference of Governmental and Industrial Hygienists (ACGIH). 1990. *Documentation of the Threshold Limit Values and Biological Exposure Indices.* Cincinnati, OH.

Agency for Toxic Substances and Disease Registry (ATSDR). 1991. *Guidance for the Preparation of a Toxicological Profile.*

Howe. R.B. 1991. Personal communication, telephone conversation with W. Stiteler. Syracuse Research Corporation. January 30. 1991.

APPENDIX D

RADIATION REMEDIATION TECHNOLOGIES

This appendix presents two exhibits designed to assist the RPM with the process of using risk information to evaluate and select remediation technologies for sites contaminated with radioactive substances. The first exhibit, Exhibit D-1, summarizes the potential routes by which radioactivity may be released to the air, ground water, surface water, or other media when remedial technologies are implemented. Similar to Exhibit A-2 in Appendix A. Exhibit D-1 groups process variations with similar potential release mechanisms under the technology categories. Exhibit D-1 includes ground and surface water releases under the "water" column, and includes other unique release mechanisms under the "other" column. The reader is referred to EPA's report, *Assessment of Technologies for the Remediation of Radioactively Contaminated Superfund Sites* (EPA/540/2-90/001), for descriptions of each technology listed in Exhibits D-1 and D-2.

The second exhibit, Exhibit D-2, presents a qualitative estimate of the potential short-term risks posed by each technology during its implementation phase, and its potential long-term risks anticipated after cleanup. Potential short-term risks and potential long-term risks are classified as being low, moderate, or high, or some combination of these levels. This classification scheme is based on the potential for releases of radioactivity arising from the use of these technologies to lead to potential short- and long-term risks. Under this scheme, "low" means a low potential for releases of radioactivity assuming a reasonable worst-case scenario and therefore, a low potential for human health or environmental risk. "Moderate" means a moderate potential for release and risk, and "high" refers to a high potential for release and risk.

Although the determinations of low, moderate, and high potential risks presented in Exhibit D-2 are based on the professional judgment of experienced risk assessors, they are provided only to the RPMs for making preliminary technology screening decisions. The actual risks associated with a remedial alternative at a specific site must be evaluated on a case-by-case basis. That is, technologies rated as high potential risk should not necessarily be eliminated from consideration, nor should technologies rated as low potential risk be considered safe, without evaluation of site-specific factors.

The Agency recognizes that other determinations of degree of potential risks are possible and may be acceptable. (In fact, if remediation technologies are properly designed and excuted, few, if any, of the potential releases and risks may be expected.) Therefore, the RPM is encouraged to consider all qualified sources of technical information when selecting a radiation remedial technology based on site-specific conditions.

Potential releases of mixed radioactive and nonradioactive hazardous substances are not covered in this appendix due to the limited number of technologies currently available, and the complexities involved in identifying release pathways and mechanisms. Because releases of mixed waste contaminants will warrant additional risk evaluation and considerations, RPMs should consult with a radiation protection specialist prior to selecting a remedial design for these types of sites.

EXHIBIT D-1

POTENTIAL RELEASES OF RADIOACTIVITY ASSOCIATED WITH
RADIATION REMEDIATION TECHNOLOGIES

Technologies[a]	Air	Water[a]	Other[b]
SOIL AND SLUDGE TECHNOLOGIES			
Natural Attenuation (Non-treatment Action)	• Potential emissions of radioactive particulates and volatiles	• Continued migration of radionuclides to ground water and possible transport to surface water	• External radiation exposure due to gamma emitting radionuclides in soil
Soil Handling			
Soil Excavation, Transport, and Offsite Disposal	• Resuspension of radioactive particulates • Enhanced emissions of volatile radionuclides	• Enhanced runoff or leaching of radionuclides to surface water or ground water	• Seepage/runoff to soil • Enhanced external radiation exposure of workers during excavation, handling, shipping, and disposal • Offsite migration of radioactivity due to transport by contaminated vehicles or equipment
Soil Washing, Extraction, & Bioremediation			
Soil Washing with Water	• Resuspension of radioactive soil particles and enhanced emissions of volatile radionuclides during handling and treatment	• Spills, leaching, and/or runoff of residual radionuclides in washed soil or in process water • Accumulation of dissolved or suspended radionuclides in recycled water/solvents	• Enhanced external radiation exposure from gamma emitting radionuclides in soil

(Continued)

POTENTIAL RELEASES OF RADIOACTIVITY ASSOCIATED WITH
RADIATION REMEDIATION TECHNOLOGIES

Technologies[a]	Air	Water[a]	Other[b]
Soil Washing, Extraction, & Bioremediation (Continued)			
Chemical Extraction	• Potential emissions of volatile chemicals and radioactive particulates and volatiles during handling and treatment	• Spills, leaching, and/or runoff of residual radionuclides in process water • Accumulation of dissolved or suspended radionuclides in recycled water/solvents	• Spills or leakage of extract with high concentrations of radioactive contaminants and solvents from storage tanks
Bioremediation	• Areal or fugitive emissions of radioactive particulates and volatiles • Exhaust stack emissions of incinerated biosorbants containing residual radioactivity	• Discharge of process water containing residual radioactivity • Inadvertent spills or leaching of radionuclides	• External radiation exposure from biomass containing residual gamma-emitting radionuclides
Immobilization			
Capping	• Continued emissions of some volatile radionuclides after capping	• Leaching and horizontal migration of radionuclides to ground water with rain water infiltration	• Partial reduction of external radiation exposure

(Continued)

POTENTIAL RELEASES OF RADIOACTIVITY ASSOCIATED WITH
RADIATION REMEDIATION TECHNOLOGIES

Technologies[*]	Air	Water[*]	Other[*]
In-situ Vitrification	• Volatilization of certain radionuclides during treatment • Cracks or fissures in vitrified mass may act as conduits for the release of volatile radionuclides	• Possible leaching and migration of radionuclides to ground water due to soil matrix destabilization	• External radiation exposure in radium contaminated soils due to the buildup of radon decay products
GROUND WATER AND SURFACE WATER TECHNOLOGIES			
Natural Attenuation (Non-treatment Action)	• Potential buildup of volatile radionuclides (eg, radon) in ground-water and municipal water distribution systems	• Continued transport of radionuclides to the aquifer and possible discharge to surface water	• Potential deposition of radioactive sediments in surface water over large areas (eg, river basins)
Filtration	• Fugitive emissions of volatile radionuclides	• Discharge of effluent water containing dissolved radioactive solids	• Potential leaching of radionuclides from filter cakes or sludge • External radiation exposure from radioactive cakes or sludge
Granular Activated Carbon Adsorption	• Potential stack emissions of volatile radionuclides upon saturation or breakthrough	• Discharge of treated water containing residual radioactive contamination • Possible release of radionuclides due to backflushing and/or regeneration	• Potential external radiation exposure due to the sorption and buildup of gamma-emitting radionuclides
Ion Exchange	• Potential for off-gassing of volatile radioactive decay products from parent nuclides on resin columns	• Discharge of treated water containing residual radioactive contamination • Possible release of radionuclides due to backflushing or regeneration	• Potential external radiation exposure due to the buildup of gamma-emitting radionuclides

(Continued)

EXHIBIT D-1 (Continued)

POTENTIAL RELEASES OF RADIOACTIVITY ASSOCIATED WITH
RADIATION REMEDIATION TECHNOLOGIES

NOTES

* Source for radiation remediation technologies: US Environmental Protection Agency (EPA). 1990. *Assessment of Technologies for the Remediation of Radioactively Contaminated Superfund Sites.* EPA/540/2-90/001.

* In general, seepage and leaching are more likely to affect ground water, but could also lead to surface water contamination. Runoff and discharge are releases that will most likely contaminate surface water, but may also lead to ground-water contamination.

* Other releases include treatment residuals requiring further remediation and/or special handling and disposal considerations. External radiation exposure due to the presence of gamma-emitting radionuclides in treatment residues should also be considered as a potential human health exposure pathway, even though this pathway does not involve the physical release of radionuclides into the environment. The risk assessor should also consider other common technologies used to remediate ground water and surface water contaminated with radioactive substances, such as aeration, evaporation, distillation and solvent extration, not included in Exhibits D-1 or D-2.

EXHIBIT D-2

DEGREE OF POTENTIAL SHORT- AND LONG-TERM RISKS ASSOCIATED WITH RADIATION REMEDIATION TECHNOLOGIES

Technologies*	Potential for Short-term Risks	Potential for Long-term Risks	Comments
SOIL AND SLUDGE TECHNOLOGIES			
Natural Attenuation (Non-treatment Action)	High	High	• The No Action alternative will not meet the two NCP threshold criteria: (1) protection of human health and environment, and (2) compliance with ARARs • Migration and release of radioactive contaminants would be expected to continue unless abated or mitigated
Soil Handling			
Soil Excavation, Transport, and Offsite Disposal	Moderate/High	None/Low	• During excavation, the potential for short-term radiation risks to remedial workers onsite and to the general public offsite may be moderate to high • Once the source or sources of radioactivity has or have been removed, the potential for long-term risks should be minimal or non-existent, depending on the level of residual radioactivity remaining onsite
Soil Washing, Extraction, & Bioremediation			
Soil Washing with Water	Moderate	Low	• During excavation and soil washing, the potential for short-term radiation risks to remedial workers onsite and to the general public offsite may be moderate • Depending on the level of residual radioactivity remaining, the potential for long-term risks may be low to moderate
Chemical Extraction	Moderate/High	Low/Moderate	• During excavation and chemical extraction, the potential for short-term radiation risks to workers onsite and to the general public offsite may be moderate to high • The potential for long-term risks depend upon the chemical and radiological characteristics of the treated soil recycled back into native soil

(Continued)

-62-

EXHIBIT D-2 (Continued)

DEGREE OF POTENTIAL SHORT- AND LONG-TERM RISKS ASSOCIATED WITH RADIATION REMEDIATION TECHNOLOGIES

Technologies*	Potential for Short-term Risks	Potential for Long-term Risks	Comments
Soil Washing, Extraction, & Bioremediation (Continued)			
Bioremediation	Moderate	Moderate	• Accidental spillage of radioactivity from biotreatment solutions, off-gassing of volatile radionuclides, and elevated external radiation exposures may contribute to the potential for moderate short-term radiation risks • Long-term risks depend upon the chemical and radiological characteristics of the treated soil recycled back into native soil In general, these risks should be low to moderate
Immobilization			
Capping	Low/Moderate	Moderate/High	• Short-term radiation risks to workers and offsite populations should be low to moderate, provided that the source or sources of radioactivity are not excavated before capping • Since the sources of radioactivity will be left in place, long-term risks to human health and the environment may be moderate to high depending on the extent to which the cap is capable of preventing the migration of radionuclides in the future
In-situ Vitrification	Moderate/High	Moderate	• Initially, both radiation and physical hazards contribute to the moderate to high potential for short-term radiation risks posed by the use of this technology, primarily to onsite workers • Since the stability and long-term integrity of vitrified soils containing radioactive materials remain unverified in the field at the present time, and since the buildup of radon decay products in vitrified soils may increase external exposure rates with time, potential long-term radiation risks to the general public may be moderate to high

(Continued)

EXHIBIT D-2 (Continued)

DEGREE OF POTENTIAL SHORT- AND LONG-TERM RISKS ASSOCIATED WITH RADIATION REMEDIATION TECHNOLOGIES

Technologies[*]	Potential for Short-term Risks	Potential for Long-term Risks	Comments
GROUND WATER AND SURFACE WATER TECHNOLOGIES			
Natural Attenuation (Non-treatment Action)	High	High	• The No Action alternative will not meet the two NCP threshold criteria: (1) protection of human health and environment, and (2) compliance with ARARs • Releases of radioactive contaminants to ground water and surface water would be expected to continue unless abated or mitigated
Filtration	Low/Moderate	Low	• The potential for short-term radiation risks to workers and the public will depend on a number of factors, including: (1) the concentrations of radionuclides in the ground or surface waters; (2) the efficiencies of filtration systems; (3) the breakthrough time; and, (4) the change-out or regeneration cycle time. In general, these potential risks are expected to be low to moderate • The potential for long-term risks will also depend on the factors listed above, but will depend primarily on the concentration of radionuclides in ground water or surface water remaining to be treated (ie, concentrations (and risks) may be expected to fall off with treatment). Potential risks to the general public may be expected to be low. The handling and disposal of filter materials and sludges containing radionuclides may pose risks to workers if radioactivity concentrations exceed federal or state standards

(Continued)

DEGREE OF POTENTIAL SHORT- AND LONG-TERM RISKS ASSOCIATED WITH RADIATION REMEDIATION TECHNOLOGIES

Technologies*	Potential for Short-term Risks	Potential for Long-term Risks	Comments
GROUND WATER AND SURFACE WATER TECHNOLOGIES			
Granular Activated Carbon Adsorption	Low/Moderate	Low	• The buildup of radon and radon progeny on activated charcoal may increase both potential short- and long-term risks of external radiation exposures to workers Regeneration of GAC may release radionuclides that are not well sorbed Disposal of spent GAC containing elevated concentrations of lead-210 (and chemical contaminants) may pose handling problems Buildup of radon and other radionuclides on GAC also depends on: (1) the concentrations of radionuclides in the ground or surface waters; (2) collection efficiencies; (3) GAC breakthrough time, and; (4) the change-out or regeneration cycle time
Ion Exchange	Low/Moderate	Low	• Similar to the potential risks posed by the treatment of radionuclides in ground water and surface water using filtration or carbon absorption techniques, the potential for short- and long-term risks posed by the collection of radionuclides on ion exchange resins depends primarily on the radionuclide-specific collection efficiency and water concentrations In general, these potential risks may be low to moderate

* Source for radiation remediation technologies: U.S. Environmental Protection Agency (EPA). 1990. *Assessment of Technologies for the Remediation of Radioactively Contaminated Superfund Sites*. Office of Solid Waste and Emergency Response. EPA/540/2-90/001.